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THESIS

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Theater Airlifter Survivability on the Ground

THESIS

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Preface

This thesis presents the results of initial study of the threats that tactical airlifters will face during ground operations at forward bases. The work concentrated on the ground based threat; the weapons evaluated were chosen based upon widespread use by armies throughout the world. The research was undertaken at the Air Force Institute of Technology (AFIT), Wright-Patterson Air Force Base, Ohio.

I would like to thank the faculty and staff members of the Air Force Institute of Technology, in particular my advisor Major Dennis Dietz and my reader Major James Shedden.

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Michael Alan Silver

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Abstract

Airlifter attrition can severely decrease the throughput of cargo during extended airlift operations. Much work has been done to enhance the tactical airlifter survivability in the air but little study has gone into airlifter survivability on the ground, especially when the threat is from enemy ground forces.

This thesis develops a method to measure the threat to a parked aircraft from ground threats such as artillery and infantry weapons. Simplified attack scenarios are constructed to model attacks by specific weapons. Specific scenarios cover airlifter mobility on the ground, time to off-load cargo, the short-field takeoff capability of the aircraft, and attack by direct-fire infantry weapons. The weapons are evaluated at several different ranges to target. The ranges considered are specific to the weapon based upon its maximum and minimum effective ranges. The threat to the aircraft is then measured using the probability that the aircraft is destroyed. An aircraft is considered destroyed if an incoming round hits the aircraft, or if the round impacts close enough to destroy the aircraft with blast and fragment damage.

Data for the accuracy and lethality of ground based attackers originates from several U.S. Army sources including weapons manuals, ballistic data, and operations manuals. Results of the research are used to evaluate several ideas currently under study including design improvements for tactical airlifters and security procedures for forwardly deployed aircraft. Also, information is presented regarding the factors that have the greatest impact upon ground survivability.

Theater Airlifter Survivability on the Ground

I. Introduction

1.1 Background

The changing role of tactical airlift, the resupply and deployment of personnel and material within a theater of war, means future airlift aircraft will be operating in areas near or even beyond the forward line of troops (i.e. the "front"). These changing circumstances raise questions about the survivability of the aircraft, especially while the aircraft are on the ground.

Airlifters today operate in an environment much different from when airlift was first put into widespread use during World War II. No longer do these aircraft operate solely along well protected air routes, nor do they always have large airports to use. This means that modern transport aircraft must be better able to operate in adverse conditions both in the air and on the ground. In future conflicts our forces must be ready to fight a war which minimizes any disadvantage we would face because our troops are outnumbered. Future battles will most likely not have front lines of World War I vintage but instead will be a fluid series of deep thrusts into enemy territory combined with battles in which our forces are inserted into enemy territory and then extracted at a later time(26:1-2). Airlifters in this new kind of war may well be called upon to operate in a "retail" sense, delivering directly to the user. Typical operations may entail building up a concentration of forces, supplying them throughout the operation, and then retrieving the personnel and their supplies when needed, all of this done in, or close to an area of combat.

1.2 Problem Statement

Direct support of ground forces by tactical airlift increases the mobility and striking power of deployed troops; however, the lack of analysis into airlifter survivability on the ground, in a forwardly deployed area, hampers our ability to predict and understand the possible outcomes of such tactics. This study will investigate ground survivability of tactical airlifters in order to assess the feasibility of using the different available aircraft, and determine which aircraft design characteristics and operating procedures (of those examined) most significantly affect that aircraft's survivability.

1.3 Scenario

This thesis examines the survivability of aircraft on the ground at either a temporary (opportune) airfield, or at an established airfield. The airfield may be located anywhere in a theater of operations including a position beyond the forward line of allied forces. The battle is an offensive incursion into enemy-held territory lasting for thirty days. This thesis will be used in conjunction with current work being done to develop future airlifters (20)(15). This ongoing work uses the Generalized Air Mobility Model (GAMM) as a primary investigative tool. To be easily assimilated into the current efforts, this study follows many of the assumptions made in GAMM. Although the techniques and conclusions are suitable for battle in any part of the world, specific mention is made of the Southwest Asia (SWA) theater of operations for clarity and relevance as this is currently the area of operations most heavily being studied.

1.3.1 Airfield Description. A large number of airfields simulated by GAMM are single landing strips with single parallel taxiways. There are no limits on the unloading area which the model considers infinitely large. For purposes of this study the airfield length is approximately 3000 feet long and 60 feet wide, since these

dimensions are given as desired minimums for a C–130 (9:29). The C–130 Hercules is the standard medium lift transport aircraft used by the USAF and is the aircraft used in this study.

The parallel taxiway is approximately the same width and length as the runway, and is located 100 feet from the runway with a 100 foot wide unloading area running along the entire length of the taxiway on the side opposite the runway. With this setup there is an area approximately 400 feet by 3000 feet where up to three aircraft may be located (see figure 1.1). GAMM considers the off-loading area the only area where an aircraft may load or unload supplies.

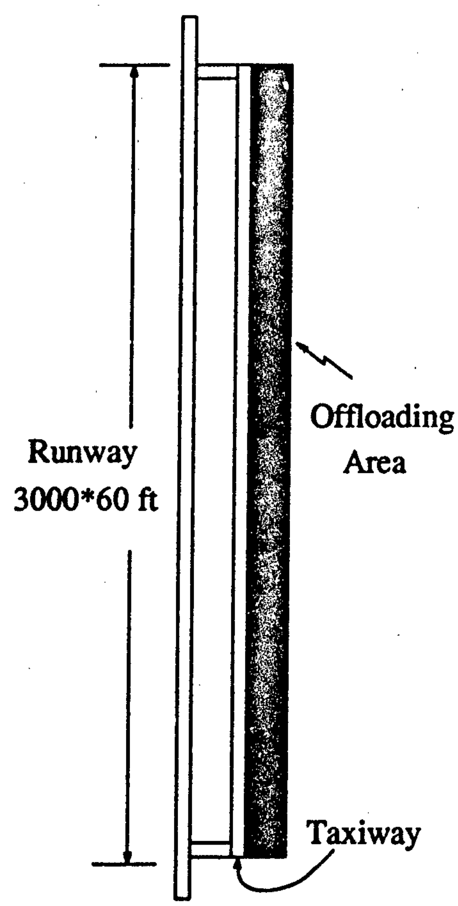


Figure 1.1. Representative airfield.

GAMM also considers the use of opportune sites for airlift operations. An opportune site is an austere or unimproved site that can support aircraft operations for a limited time. Examples of opportune sites are sections of roads or cleared fields. This type of airfield is considered important to the airlift operation because it greatly increases the number of landing areas available in the area of the ground operations. The number of opportune sites available for use varies greatly with the takeoff and landing performance of the aircraft.

1.3.2 Methods of Attack. Effective coverage of the entire area of an airfield would require the use of artillery or a very large number of mortars. Since it is unlikely that a large number of mortars would be massed specifically for this type of attack, we consider two other types of mortar attack. The first type is zone fire. This consists of several mortars acting together to lay down fire over a preplanned rectangular grid. The largest standard grid is approximately 200 meters wide(4:135), requiring four mortars. By using three mortars, each firing at range increments of fifty meters, it would be possible to cover an area of over 100 by 150 meters in about a minute using close to 100 rounds. The second type of mortar attack uses an observer who is in visual contact with the airfield and can communicate to the mortar crews. In this scenario the mortar crew fires a 'best guess' round to where he thinks the aircraft is, and the observer then corrects his fire. With a well trained observer and mortar crew, having a good idea of where the aircraft is in relation to the mortar, it is quite feasible to straddle the target with the first two shots and then split the difference and send a barrage of shells to destroy the target. With less able soldiers it might take several more rounds before they find their target.

The large size of the airfield relative to the small number of aircraft that could possibly be there at any time, complying with the maximum aircraft on the ground (MOG) number, makes observer fire the most efficient way to destroy aircraft on the field. If it were possible for the enemy to place an observer team in a good position to view the airfield, three good mortar teams could quite conceivably destroy three

parked aircraft in less than two minutes. This short time from initial attack to destruction of the aircraft precludes the evacuation of any of the aircraft that do not already have engines running and are prepared to move immediately. The obvious counter to this type of attack is to deny the enemy good observation points. The ability of our forces to control these vantage points depends greatly on the type of terrain and the amount of urbanization in the airfield's vicinity. If the airfield were overlooked by large numbers of multi-story buildings or surrounded by mountainous terrain, it might be impossible to completely deny access to the enemy. This task is further complicated because a concealed observer has no need to carry any weapons, but only a radio powerful enough to communicate with the mortar or artillery units.

Zone fire for mortars is clearly the less desirable choice, but because it is very easy to accomplish from medium and long ranges rather effectively, it is not unreasonable to expect this type of attack. The appeal of a zone fire attack by mortars is that a light mortar team could set up within range of the airfield, use maps to lay down a quick barrage of fire, and then withdraw before our security forces could locate and destroy the team. This type of attack occurred in Vietnam on several occasions with mixed results. However, experience from Vietnam has limited relevance since airlift operations usually involved fixed airfields where sizeable numbers of aircraft were clustered together for ease of service. Since the temporary airfields only exist to receive materiel and personnel, there is no need to bunch up the aircraft in any way. Therefore, for a 3000 foot taxiway with off-loading areas along the entire length of the airfield and a MOG capacity of three, we can expect approximately 1000 foot spacing between off-loading aircraft. This large spacing reduces the effectiveness of a zone fire attack.

Attacks by field artillery are accomplished in a manner similar to zone fire for mortars. A standard battery of five artillery pieces will fire so as to place the incoming rounds at set distances from each other. The distances between the aim-points are determined by a lethal radius predetermined for each munition type. Those distances

are taken from the appropriate Army field manuals(5). Field artillery has several standard methods of attacks. The one used in this study is the "standard sheaf". The standard sheaf places the aim-points for each individual gun closer together than usual to compensate for differences in muzzle velocities of the guns (due to wear), and for the dispersal of the guns. The guns are assumed to be dispersed over some distance as this will increase the survivability of the individual guns in the case of counter-battery fire. Counter-battery fire is a radar directed artillery attack designed to destroy enemy indirect-fire capability. It finds the enemy guns by tracking the trajectory of the incoming rounds back to their source. The airfield itself would not be equipped to engage the enemies guns, but allied forces located near the airfield would likely have this potential.

An air attack on an airfield must be considered possible unless our forces have almost complete control of the skies or the enemy air forces have been reduced to a point where a small airfield is no longer a valuable enough target to risk the loss of combat aircraft. Both guided and unguided munitions are available to most modern air forces and because of the relative vulnerability of the parked aircraft to external blast damage, attrition can be expected to be high in an accurate attack by aircraft. Specialty munitions such as cluster bombs (CBU), which throw out hundreds of sub-munitions over a large area, would completely destroy any aircraft caught in its lethal radius. Anti-runway munitions, as used in this study, are purely for the purposes of cratering the runway and do not damage aircraft. Air attacks are not specifically addressed in this study but similar analysis techniques could be used to determine the lethality of aircraft-weapon pairings. Data is currently not available to measure the dispersion of air-launched (or dropped) weapons.

1.3.3 Airbase Defense. Security of the airbase and its perimeter is the duty of Air Force Security Police. Current philosophy is a three layered defense of the airbase designed to detect, delay, and destroy any hostile force attempting to infiltrate the area(23). The outermost defense consists of listening and observation

posts (LP/OP). These posts are located at the maximum range of enemy weapons (as determined by intelligence units). The singly manned LP/OP is responsible for identifying hostile forces and guiding security forces to intercept and destroy them. The second layer of defense is a mobile screening force. The screening force is used to engage infiltrators, destroying them if possible. If the screening force is unable to destroy the infiltrators, they act as a delaying force, holding the enemy until reinforcements arrive. The third layer of defense is the mobile reserve, responsible for reinforcing other security units and for final defense of the aircraft. The overall defense of the airbase depends on the resources that need to be protected, in rank order of importance to continue air operations. Furthermore, airbase defense is tailored to take advantage of terrain and any resources available at the base.

Security police deploy in teams of thirteen or forty-four men or in special teams. The different special teams are: dog teams with six men and six dogs, Mk 19-automatic grenade launcher teams (usually vehicle mounted), 81mm mortar teams, and Stinger surface-to-air missile teams. Weapons normally carried by security police are M-16 rifles, M-203 grenade launchers, M-60 medium machine guns, .50 calibre heavy machine guns, and claymore mines. Individual security policemen are qualified in other weapons and will use them when available. The number of security police deployed to an airfield is based on a threat assessment performed by intelligence units.

Current doctrine stipulates that airbase defense is the sole responsibility of Air Force Security Police. In an actual situation where airfield operations are in close proximity to ground fighting, it is likeiy that Army units would be assigned to assist with airbase defense as happened during the Vietnam War.

1.3.4 The Airfield as a Target of Opportunity. An aircraft on the ground is a soft target and almost any type of weapon can cause significant damage within its effective range. This fact coupled with the high priority of aircraft as targets,

makes the attack by weapons not usually thought of as anti-aircraft weapons quite realistic. Weapons such as anti-tank guided missiles (ATGMs), recoilless rifles, and other direct-fire weapons become a threat to aircraft on the ground. An ATGM, with its shaped charge warhead (designed to penetrate thick armor) would decimate an aircraft inside and out with a molten stream of metal. A recoilless rifle, also designed for use against armored vehicles, would destroy the structural integrity of an aircraft with its high explosive warhead. Unguided battlefield anti-armor missiles also pose a considerable threat. Although these weapons have less range and are less accurate than guided missiles, the extremely large size of a parked aircraft relative to ground vehicles makes the aircraft an easy target for a trained soldier. Since all these weapons are also capable of hitting moving targets, aircraft taxiing, in the initial takeoff roll, or slowing down after landing are also vulnerable. For the most part these weapons would cause no damage if they did not actually hit the aircraft. Even a round striking the ground very close to the aircraft would not cause major damage because these weapons have very small blast radius. The only visible damage from an anti-armor weapon striking the ground would be a small hole about six inches wide.

1.3.5 Damage to the Runway and Taxiway. The airfields that are considered usable for temporary operations may consist of only a road or a cleared strip in the desert sand, as happened in Desert Storm(17). Artillery shells are capable of blasting craters fifteen feet wide and eight feet deep into a concrete surface. Heaved sections of runway and other damage that would prevent an aircraft from taxiing could effectively double the radius of damage caused by the attack. The relative softness of these opportune airfields increases the need for availability of a runway repair team. If the airfield is in a large, open area, it may be possible to simply go around the damaged areas. In more constricted airfields it would be necessary to repair the damage before aircraft could arrive or depart.

GAMM contains a subprogram that models runway attack and repair. Output from this subroutine contains frequency of attacks against the runway, number of cuts made in the runway, and time to repair the cuts. Anti-runway munitions shorten the usable runway by cutting the landing surface with craters. If successful, the field becomes unusable to any aircraft that is not able to land and take off in the shorter sections of usable runway available after an attack. These runway attacks increase the attrition of aircraft using the field by increasing the chances of a crash or stranding aircraft on the ground. Artillery and mortars are most effective against targets such as aircraft when detonated at a height approximately equal to the height of the aircraft. Because of the height of the burst, it is assumed that attacks against the aircraft do not harm the runway or taxiway.

1.4 Research Objectives and Questions

The primary objective of this thesis is to support the Future Theater Airlift Study (FTAS) by identifying aircraft characteristics and operating methods that will increase aircraft survivability while on the ground. The results of this study will assist in the derivation of probabilities of survival for airlifters on the ground. Survivability being an important attribute for theater airlift operational effectiveness analyses(27). Specific questions being addressed in this study ask which weapons are most lethal to the aircraft, which performance characteristics are critical to aircraft survivability, and which weapons and tactics are the most severe threats to the aircraft and the bases.

1.5 Definition of Key Terms

Some terms that will be used throughout this study are defined here for clarity.

The *Generalized Air Mobility Model* (GAMM), is an interactive simulation model written in the Simscript II.5 simulation language. It is used to simulate the operations of tactical airlift within a specifically defined theater of operations.

GAMM is used by the Aeronautical Systems Center Development Planning Directorate (ASC/XR) to evaluate theater airlift system effectiveness. The outcome of this study will be used to improve the prediction capabilities of GAMM concerning an aircraft's probability of survival on the ground. Currently, most GAMM analysis is concerned with operations in the SWA theater.

The *Future Theater Airlift Study* (FTAS), formally known as the Advanced Theater Transport (ATT) and the Advanced Transport Technology Mission Analysis (ATTMA), is a long term planning project for intra-theater airlift. The objective of FTAS is to provide the analytical basis for a Mission Needs Statement (MNS) for an advanced theater airlifter. This will be accomplished by establishing a methodology for comparing alternatives, conducting trade studies over the range of potential concepts, and identifying the technologies that will be required for development of the next generation airlifter(15:2). GAMM is the primary analytical tool for FTAS.

Aircraft Survivability is a measure of the useful life expectancy of an aircraft type, especially in a combat environment. Survivability, in the post-Vietnam era, has been elevated in importance in the eyes of the military and is now a purposefully designed aircraft feature. Both the structural features and the aircraft's performance will determine a particular aircraft's survivability. Structural features which contribute to an increased survivability include the protection and redundancy of critical aircraft systems, damage control capabilities such as fire control, and the inclusion of low observability and stealth technologies to reduce the aircraft's susceptibility to the anti-aircraft threat. The aircraft's performance can also affect survivability. Within this study, an aircraft is considered survivable if it is able to take off and recover to another base.

Tactical Airlifters are military transport aircraft with the primary mission of transporting material and personnel within a theater of operations. They are contrasted with strategic airlifters that operate between different theater of operations. The distinction between these two classes of transport has become blurred with the

introduction of new aircraft like the C-17. The C-17 is designed to deploy material over strategic distances, like from the United States to Southwest Asia, and then operate as a tactical airlifter by unloading in a forward area. A forward area would be distinguished by a lack of permanent support infrastructure and possibly even the lack of an actual runway. Throughout this study, tactical, theater, and intra-theater are used synonymously.

Short Takeoff and Landing/Short Takeoff Vertical Landing (STOL/STOVL) refers to an aircraft's ability to take off and land in distances much shorter than those needed by conventional heavy aircraft. Approximate landing distances are on the order of 1500 feet or less for a fully loaded transport. Vertical landings and takeoffs would require a landing surface only as large as the aircraft itself. As the required runway length needed for takeoffs and landings is reduced to approximately 750 feet, the aircraft is termed Super STOL (SSTOL). The critical technology to these aircraft at present is the ability to produce enough thrust to operate as designed while carrying large amounts of cargo. Further research concerns identification of the best configuration of the aircraft to maximize the available engine power.

Field Artillery is the group of weapons, not including rockets and mortars, used to support ground troops. Within this weapons group are guns and howitzers. A gun fires a projectile at high velocities, and flat trajectories, over long distances; a howitzer fires a generally heavier projectile in a high and variable trajectory(1). In practice, the qualities of these two weapons are often mixed to provide a more versatile weapon. The primary role of field artillery is to provide fire support over great distances and often when the target is not visible to the firer. The high trajectories of howitzers make them well suited for firing over intervening high terrain or obstacles, and into deep valleys. Modern field artillery comes in both self-propelled and towed versions, depending on the mission of the owning forces. Modern guns and howitzers range in muzzle size (internal barrel diameter) from approximately 85mm up to 203mm (8in).

Mortars can be considered special forms of howitzers which fire only at high angles(1). A typical mortar is a smooth bore weapon supported by a bipod at the muzzle end and resting on a circular base plate which absorbs the shock from firing. The mortar is a quick reaction weapon, firing at roughly ten times the rate of large howitzers. Most mortars are designed to be man-portable by several soldiers each carrying a subsection of the weapon. Larger mortars are vehicle mounted but usually retain the components to be used away from the carrier vehicle. Small size, high rate of fire, simplicity, and cheapness make mortars very popular weapons with guerrilla forces. Man-portable mortars range in muzzle size from approximately 60mm to 120mm, vehicle mounted mortars can be as large as 240mm.

1.6 Assumptions

Under normal airfield operations, the aircraft's engines remain running. With GAMM, this means that any aircraft off-loading while hostile forces are in the vicinity will do so with engines running. If the airfield is considered to be in a high threat area, unloading will be accomplished using combat offload techniques. Combat off-loading is a procedure where the aircraft is moved forward while the cargo is pushed out of the aircraft It is a very fast way to deposit cargo. The problem with using combat off-load techniques is that the cargo denies use of the taxiway or ramp area to other aircraft until it can be removed. All loading and unloading is done in the area adjacent to the parallel taxiway. Airlift operations take place twenty-four hours a day and any type of attack is possible at any time. The field from which operations take place is considered somewhat austere. No buildings or other structures (such as revetments) are on the field to protect the aircraft from blast and fragment effects of incoming munitions. Also, because the base is only being used temporarily, repair capability is extremely limited. Therefore, if an aircraft cannot take off it may be abandoned although it remains a target for the enemy who may not be aware of its condition. The airfield is protected by security forces who will secure the largest

possible area around the field based upon doctrine and manpower. The effects of a detonating munition are assumed to form a sphere of lethal effects equally in all directions from the point of impact. The cargo aboard the airlifter and in the vicinity of the offload operations is considered to be inert, so damage from secondary explosions is not examined. Because the airbases under study are considered to be in high threat areas, all routine maintenance and refueling operations will occur at other bases.

1.7 Scope

This thesis concerns itself with the period of time that a tactical airlifter is on the ground. The study uses the C–130 Hercules tactical transport aircraft as the primary tactical transport in use. Weapons that will be considered in the threat include both indirect fire (i.e. mortars and artillery) and direct fire weapons (i.e. machine guns, rockets and missiles, and heavy caliber vehicle-mounted guns). Air-to-ground weapons will not be addressed except for anti-runway munitions. The methods used to evaluate weapons will be general enough to encompass several different individual weapons with one set of computations individually tailored for each weapon. Nuclear and chemical weapons are not considered. All enemy weapons fire high explosive (HE) warheads aside from those firing shaped-charge warheads where noted.

II. Literature Review

Topics covered in this thesis can be divided into two primary categories of study, as differentiated by the current body of work. The categories are aircraft vulnerability and survivability studies and aircraft design to increase survivability. Aircraft vulnerability and survivability studies yield important inputs for the aircraft designers. The aircraft builders use the vulnerability and survivability studies as a basis to increase aircraft survivability. The threat and the cost of these design features are weighed and those features deemed cost effective are incorporated into new aircraft designs or retrofitted on aircraft currently in use.

2.1 Aircraft Vulnerability and Survivability

Research into this area is widespread and varies in scope from specific aircraft to the entire inventory of Air Force aircraft. Historical data from the Vietnam War and data collected from test firings against static aircraft are the primary sources of the statistical data used. From these sources, predictions are made on the vulnerability of an aircraft and structural features that can be developed to counter the threat. Wollaston and Brown, in their paper *VSTOL Design Implications for Tactical Transports* (26:1), repeat the need for airlifters to operate "across the breadth of the airland battlefield, with deep operations" into enemy held territory.

The authors cite Aircraft Battle Damage Repair (ABDR) as a critical technology. Its purpose is to get damaged aircraft back in action in the shortest possible time, using the fewest possible resources. Using data from the Vietnam War, it was found that for every aircraft lost, there were between two and ten aircraft that returned with combat damage(25:1). For a damaged aircraft, the length of time on the ground is directly proportional to the chances of it being destroyed. ABDR's inclusion into the algorithm that models survivability is a possible extension to this study.

The Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) (11:5.2–5.9) divides aircraft into critical areas which are considered separately in judging an aircraft's vulnerability. A subset of this list, eliminating items that do not pertain to airlift aircraft, could be used in further study which focuses on the engineering level:

1. Skin and Transparencies
2. Propulsion
3. Flight Controls
4. Fuel
5. Hydraulic Systems
6. Structures
7. Avionics and Electrical
8. Miscellaneous (i.e. Landing Gear and Crew Systems)

In support of the GAMM model, General Research Corporation and Ball System Engineering Division were contracted to develop methodology for estimating airlifter survivability on the ground(14). Their report, Airlifter Survivability on the Ground Report, used a five step approach for survivability analysis. The first step was to define the potential for airlifter encounters with a threat system through the examination of the physical environment, the threat environment, and the mission definition. The second through fourth steps, respectively, determined performance characteristics of the airlifter, vulnerability assessment, and survivability assessment. The fifth step was to determine the probability of survival by combining threat encounter potential with the susceptibility and vulnerability assessments(14:2.4.1).

The contractors proceeded to do sensitivity analysis on GAMM by varying some of the input parameters that influence the equation GAMM uses to determine survivability of a particular airlifter. This equation is $P_s(G) = P_s(AB)^{V \cdot T}$. where

$P_s(G)$ is the probability of survival on the ground, $P_s(AB)$ is the probability of survival on the ground at airbase AB, V is the vulnerability factor for the airlifter type, and T is the time the airlifter has been on the ground (in days). Two sensitivity analyses where performed. The first analysis varied T by reducing the loading time, off loading time, and time required to service the aircraft. This analysis showed that time on the ground had the most influence on aircraft survivability and tons delivered(14:27). The second analysis varied the $P_s(AB)$ and the V factors. Results from the second analysis showed that both the $P_s(AB)$ and the vulnerability factor greatly influence the total tons delivered and the number of aircraft attrited(14:32)

The Ballistics Research Laboratory reported on the damage caused by external blast without fragmentation effects in a recent report. (18). Blast vulnerability estimation encompasses a large number of techniques ranging from controlled experimentation to computer modeling of structural responses to blast. The author states that external blast is primarily effective against structures and control surfaces externally, and pilot and control rods internally(18:1). The systems that are vulnerable to damage from blast usually result in catastrophic kills when damaged. Therefore, determining whether an aircraft has been damaged from blast effects is merely a question of how much blast each critical component received, and whether this amount exceeds the tolerance of the component. This category contains any ordinance with the weight of explosive between one and 2000 pounds.

In 1983, the Lockheed-Georgia Company completed a study on the survivability of the C–130H tactical airlifter in a non-nuclear environment(16). Although the study dealt with survivability in flight, many useful results apply to ground survivability. Looking at different flight conditions (high-altitude and low-altitude), under differing flight conditions (maneuvering and non-maneuvering), the study found that the critical aircraft systems varied. The threats were anti-aircraft artillery (AAA), fighter aircraft machine guns, and fragments from surface-to-air missiles. The specific ammunition was 12.7 API, 23mm API, and 23mm HEI, for the aircraft guns

and AAA. The SAM fragments varied in size from 46 grains to 175 grains (7000 grains = 1 pound).

In all the in-flight scenarios that were examined it was found that the primary contributor to vulnerability was the fuel system(16:vi). In low-altitude maneuvering flight the next highest contributor to vulnerability was the hydraulics system, followed by the aircrew and then propulsion. High-altitude flight had the propulsion system as the second largest contributor, followed by the crew. At high altitudes the hydraulics were not considered a critical system because a manual backup system exists that would allow both pilots, working together, to recover the aircraft to the airbase.

Recommendations to increase the survivability of the C–130H included adding foam and inert gas releasers to inhibit fire and explosive effects in the fuel system. The crew's survivability could be increased by isolating them with a ballistic curtain from the area of projectile detonation. The propulsion system would benefit from armoring the throttle area and the control cables. The hydraulic system could be made more survivable by physically separating the two sets of hydraulic lines, primary and backup, and by adding more check valves and shut-off valves(16:ix).

Although less abundant than studies of airborne aircraft survivability, there are several studies that look at aircraft while on the ground. The majority of this work is done at the micro level. Highly detailed examination of of blast patterns and fragmentation effects are coupled with complex equations detailing the aircraft structure. The high level of detail usually allows only one aircraft to be examined in the course of the study.

A methodology for predicting the vulnerability and survivability of aircraft at a base subject to attack is presented in Parked Aircraft Vulnerability/Survivability Estimation Techniques(29), completed in 1978. The methodology covers conventional and guerrilla attacks against fixed and rotary wing aircraft. The threat can be modelled as surface or air launched and aircraft damage could result from blast,

fragmentation, or incendiary effects. Equations are included to allow an analyst to follow along using the same methodology to evaluate any aircraft. Large amounts of data concerning the structure of the aircraft and its critical subsystems must be obtained to use this methodology. The weapons used in the attack must also be well studied. Explosive weight and type, as well as the method of delivery and the speed and trajectory of the munition, must be calculated to keep a balanced level of detail. As an example the study used an F-5E aircraft under attack from forces equipped and trained using Soviet doctrine. Again, the large amount of data that must be input to the model limits its use to a single aircraft being attacked by a single or very few different weapons.

Two years after the Parked Aircraft Vulnerability/Survivability Estimation Techniques study was released, Southwest Research Institute delivered the Parked Aircraft Vulnerability/Survivability Assessment Procedure(30) in 1980. The assessment procedure makes use of a computer model, the Parked Aircraft Survivability/Vulnerability Model (PARK AC), to determine survivability. Three methodologies for determining the extent of damage to the aircraft are presented. The probability of fire from high explosive incendiary (HEI) ammunition uses data from 686 tests. The test data covers several different conditions, designs, and survivability enhancement devices. Probabilities are also developed for the initiation of explosion in munitions from fragment strikes, the munitions being carried on the parked aircraft. Finally, a fragmentation penetration model is presented allowing the estimation of residual velocities and energy of fragments after penetrating the aircraft skin.

The Large Parked Aircraft Survivability Study(2) examined the threat from air dropped munitions to parked aircraft. The threats were from 250 and 500 pound bombs and cluster bombs (CBU's). Having only a short period of time to complete the study, the authors looked at the spread of fragments and submunitions based upon a single angle of impact with the ground. The fragments were considered

possibly lethal if they were able to penetrate a 0.125 inch steel plate. The lethal radii were derived from the Joint Munition Effectiveness Manuals (2:13). From this data, Effective Miss Distances (EMD) were calculated. An EMD gives the distance from the aircraft at which the munition will not cause significant damage. The work focused on the probability of fragments initiating a fire or explosion in the fuel system.

A very early analysis of parked aircraft vulnerability undertook to determine the vulnerability of B-57 aircraft parked in the alert area of Bien Hoa airbase in South Vietnam(24). This study looked at mortar and unguided rocket attack by Viet Cong troops in a short attack lasting only a few minutes. The study assumed the probability of hitting an aircraft was the probability of hitting the aircraft parking area multiplied by the ratio of the size of the aircraft to the size of the parking area. Lethal radii for the attacking weapons were taken from JMEMS documents, although they do not seem to have been adjusted to account for the target being an aircraft as the data are simply the lethal radii for people. The study was a quick and dirty look at the problem. The results of the study indicated that an attack on the area of the B-57s would cause heavy losses to the aircraft and recommended either moving them or not loading them with bombs and fuel while parked so closely together. The advice of the report was not taken and, when the base was attacked, the aircraft losses were five B-57 aircraft destroyed and eight others heavily damaged (3:323). The assumption that any aircraft caught within the lethal radius of an incoming munition is destroyed is followed in this study also.

2.2 *Aircraft Design to Enhance Survivability*

Studies are continuously performed, by both the Air Force and those companies that build military transport aircraft, to increase the survivability of airlift aircraft. Presented here are some of the design features that are considered important for the

next generation airlifter and an overview of the new design features that have been included on the Air Force's newest airlifter, the C–17.

> For force multiplication, emerging battle doctrine establishes that highly mobile integrated air and land forces will be required to conduct assault and resupply sorties deep within enemy territory. Survivability is the new major design consideration for successful tactical airlift missions. (20:2)

In 1984 the Lockheed-Georgia Company, makers of the C–130 Hercules, began research into upgrading existing tactical airlifters. The areas of development were advanced STOL, survivability (while airborne), an advanced cockpit design, and electronics and avionics technologies(20:3). Their research focused on getting airlift support to the soldiers in battle. STOL performance was greatly enhanced by slightly changing the shape of the wing, enlarging flight control surfaces, adding a computer to augment flight path control, and strengthening the landing gear to allow steeper descents into the landing area. Survivability focused on the reduction of electronic emissions and the ability to operate at low levels under adverse weather/night conditions. The advanced cockpit included a heads-up-display (HUD) for the pilot, holographic imaging of terrain, and use of voice control for some systems. The cockpit improvements were meant to reduce crew workload. The electronic and avionic upgrades featured satellite receivers for precise position reporting and enhanced data transfer technology. This technology was developed to provide better coordination with the ground forces.

The benefits of these upgrades will have to be weighed to judge if they are cost effective. Although these changes are meant primarily to keep the airlifters from being shot down, they may also reduce the number of damaged aircraft which take valuable manpower and supply resources from other areas. (The aircraft that was modified in this and later studies was destroyed while attempting a landing at Warner-Robbins AFB in January 1993.)

In the later study to develop an Advanced Tactical Transport (ATT)(19), VSTOL performance is considered the most important characteristic. The reason for

this priority is survivability. Compared to a STOL airlifter, a VSTOL aircraft could unload its cargo and depart in one quarter of the time because it does not need to clear the landing area prior to unloading supplies. This time advantage would reduce the number of aircraft destroyed on the ground by departing before the enemy can bring weapons to bear on the aircraft. A VSTOL fleet of airlifters could leave their cargo where they land and not worry about clogging up the landing area. The Army would have great difficulty removing this cargo in a timely manner. VSTOL transports are also more desirable because they can put the supplies down closer to where they are needed by the troops. While the advantages to the VSTOL airlifter are clear, the technology to produce an effective VSTOL transport is not yet available. Until the technology matures, airlifters will be incrementally improved to increase their short field performance.

The next generation of aircraft to operate in the tactical environment will be the McDonnell Douglass C–17. Survivability has been designed into the C–17 from the beginning of the program, and many of the features that went into the HTTB are on board. Production aircraft will have advanced cockpits with heads-up-displays (HUD) and multi-function displays (MFD) to reduce pilot workload. Consultation with the operators of transport aircraft encouraged the C–17 designers to include many standard features which reduce the need for special logistics support for the aircraft as its mission varies (22). For instance, the C–17 will carry a supply of litters so that it can perform aeromedical evacuation without waiting for special equipment. Other self supporting features include internal jacks for changing of tires and the ability to start engines without external power. Reliability and maintainability are improved through system design and by making important systems accessible without special tools. An important ability of the C–17 is its STOL capability which allows it to land, fully loaded, in a shorter distance than a C–130, carrying a much larger load. The ability of the C–17 to operate in the strategic role, transporting cargo over vast distances, and in the tactical role, delivering cargo to forward areas,

makes the C–17 very desirable. In this way, each new C–17 brings the Air Force the capabilities of two new aircraft.

III. Method

3.1 Research Approach

The aim of this research is to examine the dynamics of how an aircraft on the ground can increase its survivability by taking advantage of its inherent capabilities. This will be accomplished by examining how an attack on the aircraft or the runway threatens an aircraft on the ground. Specific weapons will be examined in an attack appropriate to the weapon, target, and situation. Out of this investigation will come kill probabilities conditioned on the weapon, range to target, and action taken by the target aircraft.

The method of determining probabilities of kill is divided into two stages. The first stage is to determine the probability of killing an aircraft by employment of a particular weapon. The position of the aircraft on the airfield, and the range between the airfield and the weapon firing, differentiate the kill probabilities. The second stage involves building scenarios that model the actions of the aircraft during the attack. Sensitivity analysis is done by varying conditions in the scenario to capture changes in the aircraft's performance and airfield conditions. The element of time is considered to be discrete, with steps corresponding to the firing rate of the weapon being examined.

3.1.1 Probability of Kill. The probability of hitting an aircraft on the ground is determined by overlaying the appropriate dispersion rectangle over the target area of the same scale. Dispersion rectangles are grids, specific for a munition and distance fired, that describe the probabilistic distribution of where the munition will land, relative to where it was aimed. Probabilities are summed by a discrete subdivision of the dispersion rectangle into portions that overlay the aircraft. Dispersion rectangles are described in more detail in Section 3.4.1. This same method is used to determine kills from near misses by simply increasing the size of

the aircraft to account for the lethal radius of the projectile. Changing the range from the attacking weapon to the airfield changes the dispersion of the projectiles; therefore, several repetitions of the process must be performed for each attacking weapon that is examined. The firing range also affects the size of the lethal area of the munitions. At longer ranges, the lethal radius is larger because the trajectory of the shell is higher. This yields a final flight path more nearly normal to the ground surface. As the angle between the projectile's longitudinal axis and the surface of the earth decreases, more of the blast effects and shell fragments are directed into the ground or into the air. The earth absorbs the fragments and reflects the blast wave harmlessly upward. The blast above the weapon dissipates and the fragments that are propelled upward lose much of their velocity and therefore their lethality. The lethal radii listed below are approximations taken from various JMEM sources. These figures are intended to capture the changes in the weapons' lethality as the range to target changes.

Table 3.1. Lethal radii of indirect-fire weapons.

Weapon	Range (km)	Lethal Area (m)	Lethal Radius (m)
60mm Mortar	0-1.5	1	0.6
	1.5-3	6	1.4
81mm Mortar	0-2	10	1.8
	2-5	30	3.1
4.2in Mortar	0-3	20	2.5
	3-6	26	2.9
105mm Howitzer	2-5	30	3.1
	7-11	70	4.7
155mm Howitzer	3-8	35	3.3
	10-14	80	5.1
175mm Gun	6-14	50	4.0
	18-32	150	6.9
8in Howitzer	4-10	50	4.0
	12-16	100	5.6

The method of attack is guided by standard operating procedure of both the U.S. and former Soviet forces, depending upon data availability. Data for U.S.

forces is much more abundant and is used to a much greater extent in this study. Recognizing the great diversity of possible enemies and tactics, several simplifications are made concerning the conditions of the attack; these are discussed below. Multiple and single attackers are evaluated. The intelligence information available to the enemy forces is indirectly considered in the type of attack examined. In the case of an indirect fire attack with an observer directing the fire, the enemy observer has the airfield in view either by being in an advantageous position overlooking the field or by using remote or airborne sensors. This observer can then direct the incoming fire on to the aircraft or other targets on the field. If observation is not available, enemy forces may rely on topographical maps to locate probable areas of aircraft operations. With an accurate and detailed map, such as an army topographical map, a trained artillery crew could lay fire at any point they choose. The problem is that they are unable to confirm that their targets are in the area of the attack.

The attacking forces may be firing from any direction around the airfield. In the case of indirect fire this must be taken into account because the direction of fire changes the manner in which the dispersion of incoming rounds threatens different areas of the airfield. Two methods were considered to include this variability. The first method was to repeat all the lethality calculations for several directions and then aggregate the results into an overall set of data. The second option considers the direction that would offer the highest lethality as a baseline set of data for the calculations. The latter option was chosen in order to save considerable computation time and because the level of detail of the model is not high enough to warrant the extra computation. An attack of the maximum lethality provides for a balanced analysis since the study examines mostly US weapons (rather than the weapons mix expected in a specific theater of operations), and is concerned with showing broad trends in the output.

The direction of attack determined to be the most lethal is where the enemy forces are firing in a direction perpendicular to the runway. This direction is most

lethal because the expected spread of the incoming rounds can best cover all three of the areas an aircraft might be: on the runway, the taxiway, or the unloading area. This maximizes the lethal coverage of each area. The reason behind this is that range dispersion (the variation in the distance the shell is thrown) is always greater than or equal to the lateral dispersion (the lateral displacement of the shell from its initial line of flight).

The probability of hitting a target with a direct fire weapon is affected by the direction of the attack only where a change of direction changes the size of the target. That is, a soldier looking at the side of the aircraft has a larger target than a firer aiming from directly off the nose or the tail of the aircraft. The larger the size of the target, the higher the probability of a hit.

Great variability exists in the final determination of where indirectly fired projectiles will actually land. A simplification was therefore made to avoid massive duplication of effort by repeating the analysis for different miss distances. The analysis assumes that for each attack, the distances between the mean points of impact (MPI, the centers of the dispersion rectangles) are always as defined by tactics. Two different attacks are modelled. The first can be referred to as Attack I and is aimed to fall in the center of the off-loading area. This is the area where an aircraft will be located almost all of the time that the aircraft is on the ground, and is therefore the logical aim-point of enemy gunners. The centering of the attack in the off-loading area is analogous to aiming at the parking area of a fixed base, which is where airfield attacks during the Vietnam War were generally centered. For example, the 105mm howitzer is usually employed so that each howitzer aims forty meters from the next howitzer, all in a straight line(5). So, in examining the 105mm howitzer, the dispersion rectangles are centered along a row of points that form a straight line through the center of the off-loading area (Attack I). Figure 3.1 illustrates this attack. The second attack will be referred to as Attack II and is similar in all respects except that instead of being centered in the off-loading area,

it is centered between the taxiway and the runway. Attack II represents an aiming error of approximately fifty meters, assuming that an attacker will attempt to focus the attack in the off-loading area.

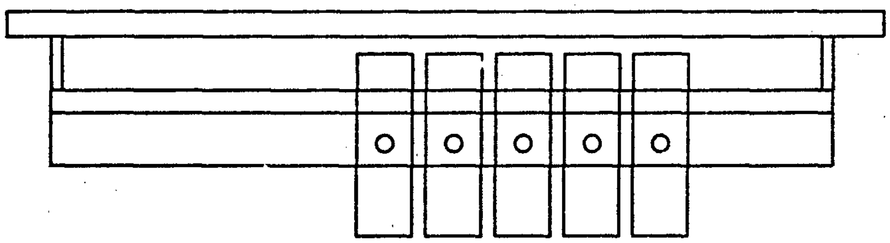


Figure 3.1. Fall of fire from attack by howitzer (Attack I) shown as dispersion rectangles with MPIs.

Mortars will fire at fifty meter intervals both laterally and longitudinally, in what is referred to as a "zone fire". The dimensions of the zone are three aim-points wide and three aim-points deep where the width runs parallel to the runway. The three shells spread laterally all arrive at the same time. The three rows of shells arrive at intervals equal to the firing rate of the mortar. This time increment is introduced because each mortar is firing a mix of shells. The shells allotted to each mortar crew are divided into three lots. The lots are differentiated by the amount of extra charge, or propellant, attached to the shell. By varying this extra charge, the ranges of the shells are changed slightly and this gives depth to the attack. This technique allows a lateral and range spread of the shells as they arrive. This technique does not work for artillery because the shells are not made to accept increments of additional propellant in this manner.

Field artillery fires at fifty meter intervals except for the 105mm Howitzer, which fires at forty meter intervals(5). The pattern of aim points is a single line of five running parallel to the taxiway and runway through the center of the off-loading area. Although these firing parameters were designed for use against personnel targets, they are standard methods which may be used against any target type, and are therefore used here. The attack will be assumed to be centered on the aircraft.

Thus, to escape the area under attack, the aircraft must taxi a distance equal to half the width of the sheaf plus one half the width of the dispersion rectangle at that range. (refer to Figure 3.2)

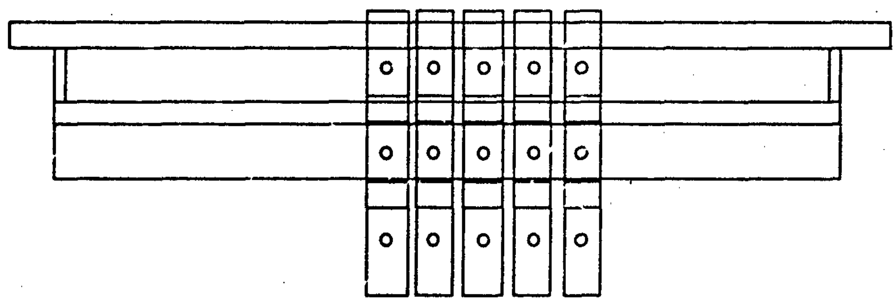


Figure 3.2. Fall of fire from attack by mortar (Attack I) shown as dispersion rectangles with MPIs.

All indirect fire weapons fire at the highest rate possible for the individual weapon; this is consistent with an attack of this kind. In the Eastern Bloc countries, this is termed *Rapid Fire*(10)[9-12]. This is slightly modified in this study where all weapons begin firing at the same time rather than as each individual weapon crew is ready.

The position of the aircraft on the field, again a simplification of a continuous function, is put into one of four positions based on the aircraft's actions and the position of the incoming fire. The use of only four positions is desirable because it greatly minimizes the necessary computations without degrading the usefulness of the output or changing the nature of the results A comparison is made with a single case using eighteen different points in Section 3.4.2. The four positions are as follows.

- Position A is the aircraft location at the beginning of each attack. The aircraft is in the off-loading area parked perpendicular to, and facing the taxiway. The longitudinal center of the aircraft (the point along the aircraft's centerline bisecting the distance from nose to tail) is approximately fifty-five meters from

where the center of a mortar or artillery attack is aimed (Attack I). The grid of points defined by the aim-points of the attacking weapons is bisected by the extended centerline of the aircraft. This places the aircraft in the lateral center of the attack. (see figure 3.3)

- Position B is the same as position A except that instead of a gun firing at a point directly off its nose, two adjacent aim-points straddle the aircraft's extended centerline, with each aim-point an equal distance from the centerline. (see figure 3.3)
- Position C places the aircraft on the taxiway. The centerline of the aircraft being approximately twenty-eight meters from where the center of an indirect fire attack is aimed. The aircraft is facing in the direction of the taxiway. The aim point of a particular gun is directly off a line perpendicular to the aircraft centerline, extending from the longitudinal center of the aircraft. (see figure 3.3)
- Position D is the same as position C except that the aim-points of two adjacent guns straddle equally, the line running perpendicular to the aircraft's centerline, through the aircraft's longitudinal center. (see figure 3.3)

Once the single shot kill probabilities have been computed, it only remains to combine them into an overall probability for the duration of the enemy attack. Since the firing rates of different weapons are different, with smaller weapons generally firing more rapidly, each weapon produces a different overall kill probability. Assuming that the fall of each incoming round is independent of other rounds fired by that particular weapon, when n rounds are fired at the aircraft(21)[75]

$$P_k^{Total}(n) = 1 - (1 - P_k^A)^e * (1 - P_k^B)^f * (1 - P_k^C)^g * (1 - P_k^D)^h \qquad (3.1)$$

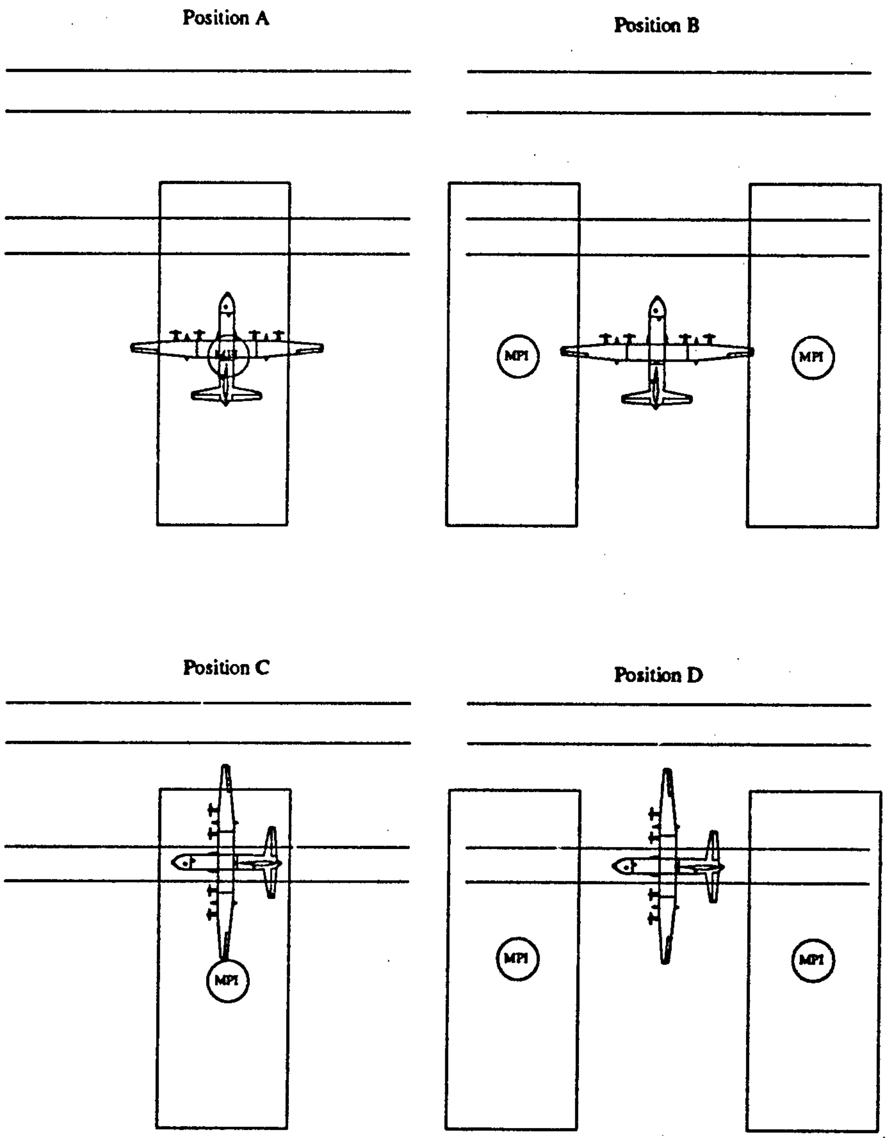


Figure 3.3. Aircraft position on airfield (Attack I).

where P_k^i is the single shot probability of killing the aircraft when it is in position i $(i = A, B, C, orD)$ and where $e + f + g + h = n$. The sum n is the total number of rounds fired while the aircraft is in the area of the attack. The number of incoming rounds when the aircraft is in position A is equal to e, the number of incoming rounds when the aircraft is in position B is equal to f, and so on. For each weapon examined, there will be a formulation of this equation with exponents determined by the rate of fire of the weapon and the aircraft's actions on the ground.

The position of the aircraft in relation to the position of the MPIs determines where the aircraft will be when subsequent salvos arrive. To more accurately model the situation, the general equation to be used in this study breaks up the P_k^{Total} into two equally weighted parts. The first part is the conditional probability of the aircraft being destroyed given that it is in Position A at the outset of the attack. The second part is conditional upon the aircraft being in Position B when the attack begins. Considering the worst case scenario, the aircraft starting in Position B will taxi toward the center MPI of the attack. This will add twenty meters to the distance required to taxi until the aircraft is clear of the area. Thus, the general equation describing an aircraft's probability of destruction is:

$$\begin{aligned} P_k^{Total}(n) &= 1/2[1 - (1 - P_k^A)^e * (1 - P_k^C)^f * (1 - P_k^D)^g] \\ &+ 1/2[1 - (1 - P_k^B)^h * (1 - P_k^C)^i * (1 - P_k^D)^j] \end{aligned} \tag{3.2}$$

where $e + f + g + h + i + j = 2n$. When mortars are the weapon being fired, the above equation changes. The method used by mortars to cover a large area is by firing a grid of shells. The depth of this grid (the distance parallel to the direction of fire) is controlled by preparing shells to travel plus or minus fifty meters from the intended center of the grid (see Figure 3.2). This slight alteration is range is easily accomplished by the use of additional propellant charges. With three mortars firing,

a grid of three rows of three bursts per row can be easily established. The advantage in using a grid is that the attack is less sensitive to errors in accuracy which increase the distance from the aircraft to a particular row of MPIs. From one row to the next, there is a time lapse equal to the time needed to fire the next shell. To account for this time lag, the equations must be modified. In this case, there is a probability of killing an aircraft located in any of the four positions from any of the three rows of aim-points.

3.1.2 Scenarios. Indirect fire weapons are used to saturate an area with ordinance quickly and efficiently. Their rate of fire is determined by the skill level of the crew, the calibre of the weapon (larger calibre weapons fire larger and heavier projectiles which take more time to load), and the limits imposed to prevent overheating which can warp the barrel and destroy the weapon. By assuming that all of the crews of a gun or mortar battery are equivalently trained, and since gun batteries are homogeneous in their weapons, it is not improper to model each salvo of projectiles as arriving simultaneously. Since the projectiles of several guns are arriving at discrete and identical time intervals, it is a simple manner to model the movements of the aircraft as discrete steps equal to the time between bursts. Varying the time to perform certain operations gives insight into the critical events that either increase or decrease the aircraft's survivability.

Three base scenarios are used. Each was designed to evaluate the effect of a single aircraft characteristic on survivability. In all cases the aircraft start out in the off-loading area, initiate taxi as soon as possible, and then taxi along the taxiway at the greatest speed they are able. The aircraft are placed in the center of the zone of fire and therefore must taxi at least half the width of the zone before insuring their safety. Each base scenario looks at just one aspect of the aircraft's ground procedure so as not to confound multiple effects.

The first scenario examines the aircraft's ability to operate on unprepared surfaces. Varying the top speed the aircraft can taxi imitates different taxiway conditions that the aircraft may need to negotiate. Although this is not the traditional way of looking at rough field capability, it is an essential part of escaping destruction in this type of situation. Obviously, the quicker the aircraft can taxi, the quicker it can move from the area under fire to the runway and depart. Three different taxi speeds are examined: 5mph, 15mph, and 30mph.

The second scenario concerns the ability to unload the aircraft quickly. If the aircraft is completely unloaded or has not yet initiated offload, the aircraft commander will be able to start taxiing almost immediately. In the case where pallets are in the process of being off-loaded, some amount of time will be required to either complete the off-load, or secure the pallets inside the aircraft. By adding one, three, or five minutes, the critical nature of the offload process is determined. Although the time it might actually take to prepare the aircraft for takeoff may take much more time, modelling very long preparation times serves no purpose because these artillery attacks will probably last no more than five minutes. One very significant assumption being made here is that the ground crew will not immediately run for cover from the attack but instead will help prepare the aircraft for taxi.

The third base scenario concerns the method of takeoff of the aircraft. This scenario will look at the advantages a VSTOL or SSTOL aircraft will have over conventional and STOL aircraft. The focus will be on the aircraft's ability to take off after an attack on the runway has cut the usable length. The frequency of the attacks and the number of effective cuts in the runway will follow the example set forth in previous studies(14)(15).

Peripheral information about the accuracy and lethality is given for direct fire weapons also. The high lethality to parked aircraft, and limited number of shots they may fire, limit the usefulness of scenarios akin to those mentioned above for the indirect fire weapons. These weapons are therefore treated on a single shot basis

and are discussed separately. Also, discussion of an observer guided mortar attack is included.

3.2 Validation of Method

Essentially the same method of determining kill probabilities was used in a Vietnam-era study of the vulnerability of aircraft based at Bien Hoa and other Republic of Vietnam airfields(24). The difference is that in this study the aircraft is not parked and will attempt to egress the area when the attack begins. Also, this study determines the probability of hitting the aircraft based on the natural dispersion of incoming munitions around the aim point rather than on the ratio of the area covered by aircraft to the total area of the parking apron. Although the Vietnam-era study is rather old, the conditions of the study very closely resemble the conditions examined in GAMM's SWA scenario. The final consideration in choosing this method of examination is time. It is the only method found that allows an assessment of survivability, given several different attack conditions, in a short period of analysis.

3.3 Accuracy of Method

Time constraints prevent an in-depth engineering study of projectile impacts and resulting damage to the aircraft and its systems. The loss of accuracy does not adversely affect the validity of the method in giving an overall understanding of possible outcomes of an attack on the type of airfield examined. Although the properties and destructive power of the munitions were sometimes estimated, the uniform way in which they were acquired will provide relative estimates of lethality for each weapon examined.

Since the time required to examine every direction and range from which an attack may come is prohibitive, the cases examined were chosen to express the capabilities of the weapons in qualitative ways. For example, mortar fire could come

from three different ranges representing close, medium, or long range fire for each particular weapon. The fall of the incoming fire could conceivably be anywhere on the field. To accommodate this (again in the case of mortars attacking with area fire) the aircraft is either outside of the zone of fire, directly in line with the incoming shells, or between lines of incoming shells. These three states represent the three areas where different levels of damage are likely to occur. This method results in a range of probabilities defined by specific data points.

This study does not identify fragment trajectories or number of perforations in the aircraft's skin and it is not intended to. The purpose of this work is to understand the driving factors in aircraft survivability on the ground. For the purposes of this study, the methods and data used are considered adequately accurate.

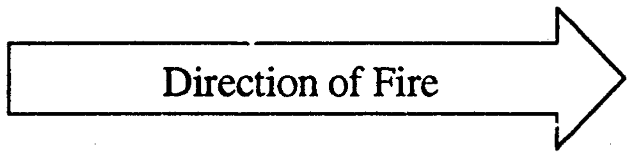
3.4 Justification

This section is divided into justification for the methods used and for the weapons and data considered in this study.

3.4.1 Method. Attacks against the airfield and aircraft are grouped into two classes, indirect-fire and direct-fire attacks. The Army groups their weapons by this classification as well. Indirect-fire weapons are combat support weapons which are usually not directly engaged with the enemy — examples include artillery, mortars, and various rocket systems. Direct-fire weapons are used in line-of-sight engagements in relatively close proximity with the enemy; weapons of this type are machine guns, guided missiles, and cannon.

Indirect-fire weapons, like all weapons, cannot place multiple rounds into one spot with a known probability. Multiple firings will cause the rounds to be dispersed a given amount from the aiming point. The size of the dispersion area is specific to the weapon and the range of fire. The greater the range, the larger the area of dispersion. The Army has laid out the probable distribution of rounds in a dispersion

rectangle(4:1;18), as illustrated in figure 3.4. Within this area, approximately 993



0.0004	0.0014	0.0032	0.0050	0.0050	0.0032	0.0014	0.0004
0.0014	0.0049	0.0112	0..0175	0.0175	0.0112	0.0049	0.0014
0.0032	0.0112	0.0256	0.0040	0.0400	0.0256	0.0112	0.0032
0.0050	0.0175	0.0400	0.0625	0.0625	0.0400	0.0175	0.0050
0.0050	0.0175	0.0400	0.0625	0.0625	0.0400	0.0175	0.0050
0.0032	0.0112	0.0256	0.0040	0.0400	0.0256	0.0112	0.0032
0.0014	0.0049	0.0112	0..0175	0.0175	0.0112	0.0049	0.0014
0.0004	0.0014	0.0032	0.0050	0.0050	0.0032	0.0014	0.0004

Figure 3.4. Dispersion rectangle with associated probabilities.

out of 1000 rounds will fall. Therefore, the use of these dispersion tables will account for over 99% of the rounds fired from a mortar or artillery piece. The United States Army publishes pamphlets which detail the operating parameters for several types of weapons. For indirect fire weapons, the manuals include estimates of probable error for a given weapon and projectile. One probable error (PE) is defined to be the distance from the mean point of impact (MPI) to the point where one half of the projectiles, on one side of the MPI, have fallen. Deflection PE is the error perpendicular to the flight path of the projectile and range PE is the error parallel to the flight path. Building a grid of eight by eight rectangles of the size specified by the probable errors yields a dispersion rectangle.

The accuracy of direct-fire weapons is distributed normally around the point aimed at in the same way as indirect-fire weapons. Data for the accuracy of these

weapons is not as easily available as that for artillery, and the data that is available is usually based on hitting a relatively small target such as a tank. Since a parked aircraft is so much larger than any land combat vehicles, this study increases the hit probability of the weapon in proportion to the relative sizes of the targets. The range of the weapon cannot be treated in the same way because range is usually reliant on the size of the propellant charge more than size of the target. For this reason, the range of direct-fire weapons is held to that given by the weapon description (see Appendix B).

3.4.2 Justifying the Four Position Method. To verify that the use of only four aircraft positions on the field would accurately model the conditions of the attack, an attack was modelled using eighteen positions. The 105mm howitzer was chosen to be modelled because its dispersion rectangles were the most random in size. This criterion was established to see if the overall P_k lines would be more linear in nature.

Instead of positions A and B, a shell could fall in any of nine positions laterally from the aircraft. The first position, centered on the aircraft, is the original position A. The other positions are at five meter increments to the side out to twenty meters. Beyond twenty meters, half the distance between MPIs, the calculations would be redundant. Twenty-five meters to the side of one MPI is the same as fifteen meters to the side of another. These calculations yield nine possible starting positions for the aircraft to be in. Four of these are redundant and are left out of the final calculations. The average of the five starting points used, matches very closely to the average of positions A and B.

As in the calculations with four positions, when the aircraft is offset from the center MPI, it taxis the longer distance to clear the area of the attack. Thus, from the five possible starting points the aircraft then taxis out onto the runway using one of the three taxi speeds of Scenario 1. Because the aircraft is not symmetric

along its centerline (nose-to-tail), all nine of the P_k's are unique for when the aircraft is on the taxiway. The equations are the same as those used for the four position method except that instead of four variables there are now thirteen. The results presented in Figure 3.5 reveal a close match with the earlier results, although the P_k's tend to be slightly lower. Each data point in Figure 3.5 represents the average of five different equations. Each equation is unique because, as the starting point moves, the distance between the aircraft and the nearest MPI changes during the time the aircraft is taxiing. A total of ninety equations were used to produce the figure. These are not included but are easily reproducible from the earlier equations.

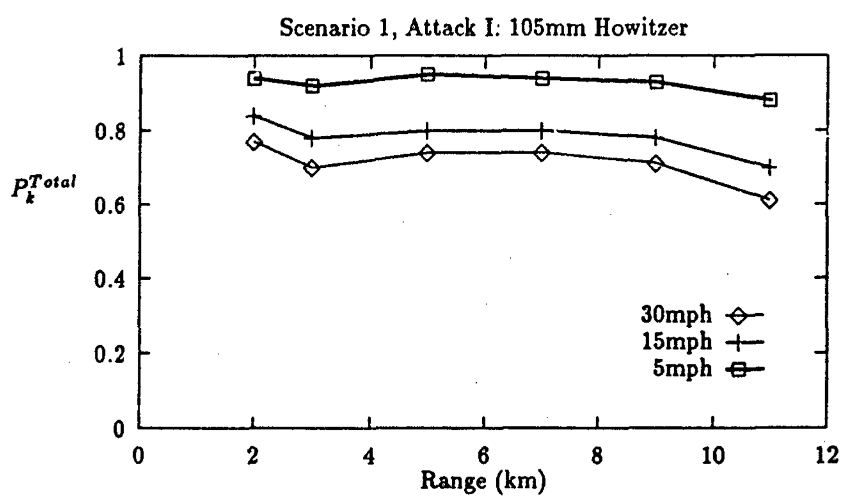


Figure 3.5. Results for the 105mm Howitzer using the multi-point method. Scenario 1, Attack I.

3.4.3 Data. Data for the accuracy and lethality of the weapons are estimates based on the Joint Munitions Effectiveness Manuals (JMEM) and U.S. Army firing tables. JMEM is a series of publications dealing with the effectiveness of weapons utilized by the armed forces of the United States and other pertinent topics. The specific weapons (especially in the indirect-fire class) are also usually of

U.S. origin unless information is available on weapons from other sources. Although it would be preferable to use data for weapons of other countries, especially those that are hostile or potentially hostile, this data is simply not available. Even if the data were available, the number of different weapons of the same type are too numerous to list, let alone analyze. Fortunately most foreign countries equip their militaries with weapons similar to those in the U.S. arsenal. Mortars, for example, are made almost universally in 60mm, 81mm, and 120mm sizes. Even accounting for different ammunition types, the size of the weapon puts tight limitations on the size and therefore the lethality of the ammunition. Also, the great proliferation of weapons throughout the world means that it is not unlikely that enemy forces might well be using equipment of U.S. origin or of similar capabilities (see Appendix B). The connection between size of the weapon and the lethality of its projectile are closely connected by the desire for greatest range and lethality possible. The size, range, and lethality, measured in size of the warhead, are all connected in the ballistics equations. Therefore, for a given gun size, range and lethality will be relatively equal for any similar make of weapon. For these reasons, the use of information about U.S. weapon systems was considered adequate for this study.

IV. *Findings*

4.1 Single Shot Probability of Kill

The tables that follow contain the single shot kill probabilities of the weapons investigated. There is a probability shown for several ranges between aircraft and weapon, and for each of the four aircraft positions as previously described. The mortar single shot kill probabilities have three subsections which determine the separate probability of killing the aircraft from each of the three rows of shells that the mortars lay down. These must be maintained separately because the rows of shells arrive at two second intervals. The first set of probabilities are conditioned on the attack being centered in the off-loading area (Attack I). The second set of data tables contain results from an attack which is centered between the taxiway and the runway (Attack II). The equations that determine the overall probability of destroying the aircraft do not change for the two sets of data.

4.1.1 Attack Centered In Off-loading Area: Attack I. The line of MPIs or the center row of MPIs run parallel to the taxiway, centered on the center of the off-loading area.

Table 4.1. Single shot probability of kill for the 60mm mortar. Attack I.

60mm Mortar-Row 1				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
100	0.00	0.00	0.00	0.00
1000	0.00	0.00	0.00	0.00
3000	0.05	0.03	0.01	0.00

60mm Mortar-Row 2				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
100	0.98	0.00	0.00	0.00
1000	0.43	0.06	0.10	0.00
3000	0.19	013	0.13	0.06

60mm Mortar-Row 3				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
100	0.00	0.00	0.25	0.00
1000	0.00	0.00	0.22	0.00
3000	0.05	0.03	0.12	0.06

Table 4.2. Single shot probability of kill for the 81mm mortar. Attack I.

81mm Mortar-Row 1				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
1000	0.08	0.00	0.00	0.00
3000	0.05	0.01	0.00	0.00
4500	0.09	0.04	0.01	0.00

81mm Mortar-Row 2				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
1000	0.70	0.00	0.19	0.00
3000	0.24	0.11	0.12	0.01
4500	0.30	0.16	0.22	0.04

81mm Mortar-Row 3				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
1000	0.08	0.00	0.51	0.00
3000	0.05	0.01	0.31	0.03
4500	0.09	0.04	0.23	0.05

Table 4.3. Single shot probability of kill for the 4.2in mortar. Attack I.

4.2in Mortar-Row 1				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
3000	0.00	0.06	0.01	001.
4000	0.01	0.09	0.02	0.02
5000	0.08	0.10	0.03	0.03
6000	0.05	0.07	0.04	0.03
4.2in Mortar-Row 2				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
3000	0.29	0.12	0.18	0.08
4000	0.18	0.19	0.14	0.11
5000	0.13	0.16	0.10	0.08
6000	0.10	0.11	0.08	0.10
4.2in Mortar-Row 3				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
3000	0.C0	0.06	0.20	0.09
4000	0.01	0.09	0.15	0.11
5000	0.08.	0.10	0.11	0.10
6000	0.05	0.07	0.08	0.10

Table 4.4. Single shot probability of kill for the 105mm howitzer. Attack I.

105mm Howitzer (M102)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
2	0.61	0.28	0.42	0.10
3	0.52	0.26	0.37	0.16
5	0.45	0.25	0.34	0.10
7	0.43	0.29	0.31	0.17
9	0.40	0.30	0.28	0.15
11	0.30	0.28	0.19	0.18

Table 4.5. Single shot probability of kill for the 155mm howitzer. Attack I.

155mm Howitzer (M109)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
3	0.44	0.19	0.37	0.00
4	0.35	0.12	0.31	0.00
6	0.38	0.15	0.32	0.00
8	0.29	0.10	0.30	0.01
10	0.38	0.10	0.30	0.02
12	0.26	0.06	0.26	0.06
14	0.21	0.06	0.20	0.07

Table 4.6. Single shot probability of kill for the 175mm gun. Attack I.

175mm Howitzer (M107)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
6	0.16	0.06	0.20	0.00
10	0.13	0.04	0.19	0.00
14	0.21	0.09	0.19	0.08
18	0.22	0.16	0.20	0.13
22	0.17	0.13	0.14	0.14
28	0.09	0.09	0.08	0.11
32	0.08	0.08	0.05	0.06

Table 4.7. Single shot probability of kill for the 8in (203mm) howitzer. Attack I.

8in Howitzer (M110)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
4	0.53	0.08	0.38	0.00
6	0.45	0.08	0.37	0.00
8	0.33	0.05	0.33	0.00
10	0.27	0.06	0.27	0.00
12	0.25	0.05	0.28	0.01
14	0.25	0.05	0.26	0.04
16	0.19	0.04	0.22	0.02

4.1.2 Attack Centered Between Taxiway and Runway: Attack II. In this case, the attack is centered at a point halfway between the runway and taxiway and parallel to both. This places the center of the attack slightly closer to the taxiway than the attack centered in the off-loading area.

Table 4.8. Single shot probability of kill for the 60mm mortar. Attack II.

60mm Mortar-Row 1				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
100	0.98	0.00	0.00	0.00
1000	0.43	0.06	0.10	0.00
3000	0.19	013	0.13	0.06
60mm Mortar-Row 2				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
100	0.00	0.00	0.25	0.00
1000	0.00	0.00	0.22	0.00
3000	0.05	0.03	0.12	0.06
60mm Mortar-Row 3				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
100	0.00	0.00	0.00	0.00
1000	0.00	0.00	0.00	0.00
3000	0.00	0.00	0.01	0.01

Table 4.9. Single shot probability of kill for the 81mm mortar. Attack II.

81mm Mortar-Row 1				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
1000	0.70	0.00	0.19	0.00
3000	0.24	0.11	0.12	0.01
4500	0.30	0.16	0.22	0.04
81mm Mortar-Row 2				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
1000	0.08	0.00	0.51	0.00
3000	0.05	0.01	0.31	0.03
4500	0.09	0.04	0.23	0.05
81mm Mortar-Row 3				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
1000	0.00	0.00	0.00	0.00
3000	0.00	0.00	0.01	0.00
4500	0.00	0.00	0.04	0.00

Table 4.10. Single shot probability of kill for the 4.2in mortar. Attack II.

4.2in Mortar-Row 1				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
3000	0.29	0.12	0.18	0.08
4000	0.18	0.19	0.14	0.11
5000	0.13	0.16	0.10	0.08
6000	0.10	0.11	0.08	0.10
4.2in Mortar-Row 2				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
3000	0.00	0.06	0.20	0.09
4000	0.01	0.09	0.15	0.11
5000	0.08	0.10	0.11	0.10
6000	0.05	0.07	0.08	0.10
4.2in Mortar-Row 3				
Range (m)	P_k^A	P_k^B	P_k^C	P_k^D
3000	0.00	0.00	0.03	0.01
4000	0.01	0.00	0.04	0.03
5000	0.01	0.01	0.06	0.04
6000	0.01	0.02	0.05	0.06

Table 4.11. Single shot probability of kill for the 105mm howitzer. Attack II.

105mm Howitzer (M102)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
2	0.02	0.00	0.49	0.11
3	0.05	0.03	0.37	0.14
5	0.08	0.03	0.44	0.19
7	0.04	0.03	0.23	0.10
9	0.07	0.05	0.28	0.10
11	0.06	0.05	0.19	0.08

Table 4.12. Single shot probability of kill for the 155mm howitzer. Attack II.

155mm Howitzer (M109)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
3	0.09	0.05	0.44	0.00
4	0.14	0.04	0.38	0.04
6	0.08	0.07	0.41	0.04
8	0.14	0.07	0.38	0.04
10	0.14	0.09	0.29	0.02
12	0.15	0.05	0.23	0.14
14	0.12	0.07	0.20	0.15

Table 4.13. Single shot probability of kill for the 175mm gun. Attack II.

175mm Howitzer (M107)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
6	0.09	0.01	0.24	0.06
10	0.10	0.01	0.20	0.04
14	0.07	0.05	0.21	0.12
18	0.15	0.07	0.21	0.16
22	0.12	0.04	0.14	0.13
28	0.08	0.09	0.08	0.13
32	0.08	0.05	0.06	0.09

Table 4.14. Single shot probability of kill for the 8in (203mm) howitzer. Attack II.

8in Howitzer (M110)				
Range (km)	P_k^A	P_k^B	P_k^C	P_k^D
4	0.06	0.03	0.48	0.00
6	0.09	0.03	0.46	0.00
8	0.14	0.07	0.38	0.00
10	0.18	0.05	0.33	0.01
12	0.15	0.05	0.29	0.07
14	0.13	0.08	0.25	0.12
16	0.10	0.07	0.21	0.04

4.2 Scenario 1

The first scenario evaluates the effects of an airlifter's ground maneuverability on its survivability. Assuming a sub-standard taxi surface, taxi speed represents the mobility of different airlifters. A large airlifter designed to operate only at fixed airbases would be extremely vulnerable to damage at an unprepared site and therefore must taxi very slowly; a smaller aircraft with protection from foreign object damage to the engines and large semi-inflated tires could taxi much more rapidly without damage. Three different taxi speeds (30, 15, and 5 miles per hour) are used for this scenario. Acceleration to taxi speeds is assumed linear with about ten seconds needed to accelerate to 30mph(17). In this scenario, the aircraft is sitting in the off-loading area with engines running and is ready to taxi. The aircraft takes approximately five seconds to initiate taxi, takes another five seconds to move forward to the taxiway (about twenty meters), and then accelerates to its maximum taxi speed.

To get a clear picture of the change in survivability, the probabilities are grouped by weapon and the results from the three different taxi speeds are overlayed on one graph. The different rates of fire for the individual weapons and the different dispersions and lethal radii of the different projectiles also vary the final

probability of kill, so each weapon has a unique output. The rates of fire for the weapons come from Jane's Armor and Artillery(13)

4.2.1 60mm Mortar. The 60mm light mortar fires high explosive projectiles at 30 RPM for a maximum of two minutes. The overall probabilities of kill for each of the three taxi speeds are presented below. The equations for the mortars differ from those for artillery because the mortars fire at three different ranges to create the grid of MPIs. This grid is reflected in the equations by the exponents. For an attack by mortar, the exponents represent the position of the aircraft (A, B, C, or D), and the row of the grid where the salvo is falling (1, 2, or 3).

4.2.1.1 30mph Taxi Speed. The first five salvos find the aircraft still in its original position. Six more salvos arrive before the aircraft is safely clear from the 100 meter wide zone. The equation for the probability of a kill is therefore

$$\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^2 * (1 - P_k^{A2})^2 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^0 \\
&\quad * (1 - P_k^{C2})^1 * (1 - P_k^{C3})^1 * (1 - P_k^{D1})^1 * (1 - P_k^{D2})^0 \qquad (4.1) \\
&\quad * (1 - P_k^{D3})^0 * (1 - (1/2) * P_k^{D3})^1] + (1/2) * [1 - (1 - P_k^{B1})^2 * (1 - P_k^{B2})^2 \\
&\quad * (1 - P_k^{B3})^1 * (1 - P_k^{C1})^1 * (1 - P_k^{C2})^0 * (1 - P_k^{C3})^1 \\
&\quad * (1 - P_k^{D1})^0 * (1 - P_k^{D2})^1 * (1 - P_k^{D3})^1 * (1 - (1/2) * P_k^{D1})^1]
\end{aligned}$$

4.2.1.2 15mph Taxi Speed. Again, the initial five salvos arrive before the aircraft has moved from its initial position. Up to seven more arrive while the aircraft is attempting to taxi clear. This gives a probability of kill of

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^2 * (1 - P_k^{A2})^2 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^1 \\
&\quad * (1 - P_k^{C2})^0 * (1 - P_k^{C3})^2 * (1 - P_k^{D1})^1 * (1 - P_k^{D2})^1 \\
&\quad *(1 - P_k^{D3})^0 * (1 - (1/2) * P_k^{D2})^1] + (1/2) * [1 - (1 - P_k^{B1})^2 * (1 - P_k^{B2})^2 \\
&\quad * (1 - P_k^{B3})^1 * (1 - P_k^{C1})^1 * (1 - P_k^{C2})^2 * (1 - P_k^{C3})^0 \\
&\quad * (1 - P_k^{D1})^1 * (1 - P_k^{D2})^0 * (1 - P_k^{D3})^3]
\end{aligned} \tag{4.2}
$$

4.2.1.3 5mph Taxi Speed. At such a slow taxi speed, far more salvos arrive during the aircraft's escape while actually moving. Five salvos arrive before moving and up to twenty more arrive before the aircraft is clear. The resultant probability of killing the aircraft is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^2 * (1 - P_k^{A2})^2 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^3 \\
&\quad * (1 - P_k^{C2})^2 * (1 - P_k^{C3})^3 * (1 - P_k^{D1})^3 * (1 - P_k^{D2})^3 \\
&\quad * (1 - P_k^{D3})^2] + (1/2) * [1 - (1 - P_k^{B1})^2 * (1 - P_k^{B2})^2 * (1 - P_k^{B3})^1 \\
&\quad * (1 - P_k^{C1})^3 * (1 - P_k^{C2})^3 * (1 - P_k^{C3})^4 * (1 - P_k^{D1})^4 \\
&\quad * (1 - P_k^{D2})^3 * (1 - P_k^{D3})^3]
\end{aligned} \tag{4.3}
$$

The results for attack A are given in Figure 4.1. Attack II results are in Figure 4.2.

4.2.2 81mm Mortar. The 81mm medium mortar is capable of 25 RPM over a period of two minutes. The equations for each taxi speed are presented below with the associated results.

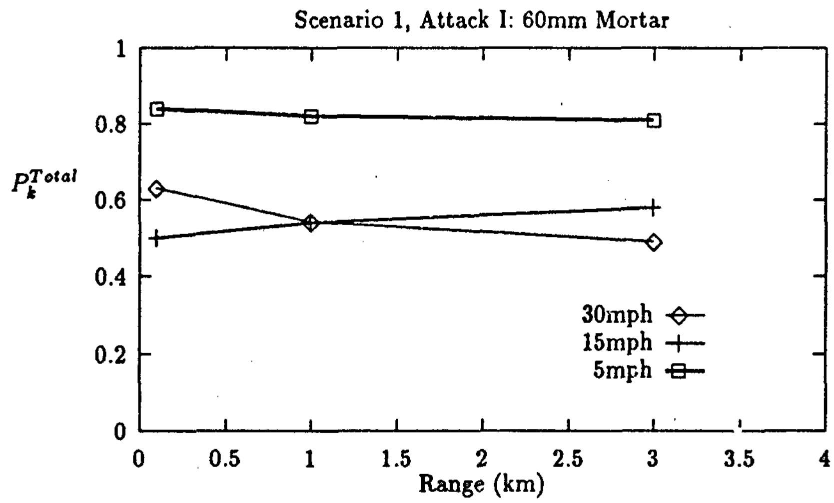


Figure 4.1. Effects of taxi speed on probability of kill with the 60mm Mortar. Attack I.

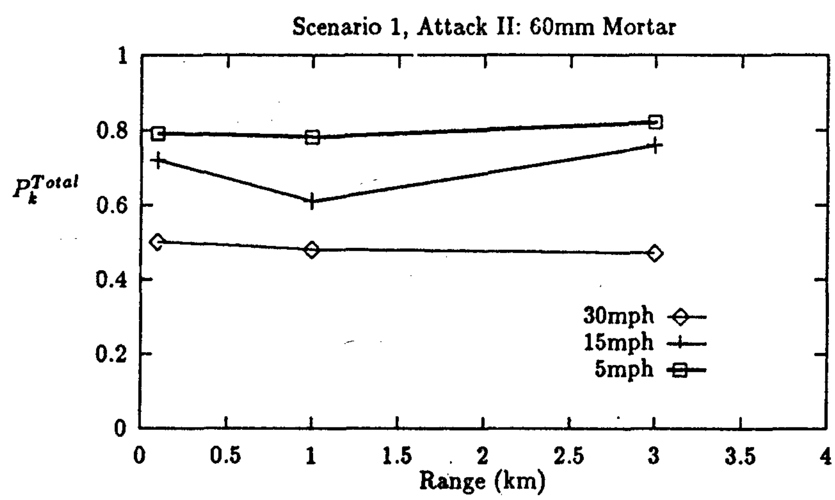


Figure 4.2. Effects of taxi speed on probability of kill with the 60mm Mortar. Attack II.

4.2.2.1 30mph Taxi Speed. At 30mph the aircraft is clear of the danger zone following the eighth salvo. The initial five salvos arrive before the aircraft has moved. The equation describing the probability of killing the aircraft during an attack by this weapon is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^2 * (1 - P_k^{A2})^2 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^1 \\
&\quad * (1 - P_k^{C2})^0 * (1 - P_k^{C3})^1 * (1 - P_k^{D1})^0 * (1 - P_k^{D2})^1 \\
&\quad * (1 - P_k^{D3})^0] + (1/2) * [1 - (1 - P_k^{B1})^2 * (1 - P_k^{B2})^2 * (1 - P_k^{B3})^1 \\
&\quad * (1 - P_k^{C1})^1 * (1 - P_k^{C2})^1 * (1 - P_k^{C3})^1 * (1 - P_k^{D1})^0 \\
&\quad * (1 - P_k^{D2})^0 * (1 - P_k^{D3})^0 * (1 - (1/2) * P_k^{D3})^1]
\end{aligned}
\tag{4.4}
$$

4.2.2.2 15mph Taxi Speed. Halving the taxi speed, in this case, doubles the number of salvos that strike during the taxiing portion of the aircraft's escape attempt. The equation for the probability of killing the aircraft is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^2 * (1 - P_k^{A2})^2 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^0 \\
&\quad * (1 - P_k^{C2})^0 * (1 - P_k^{C3})^2 * (1 - P_k^{D1})^1 * (1 - P_k^{D2})^1 \\
&\quad * (1 - P_k^{D3})^0 * (1 - (1/2) * P_k^{D1})^1] + (1/2) * [1 - (1 - P_k^{B1})^2 * (1 - P_k^{B2})^2 \\
&\quad * (1 - P_k^{B3})^1 * (1 - P_k^{C1})^1 * (1 - P_k^{C2})^2 * (1 - P_k^{C3})^1 \\
&\quad * (1 - P_k^{D1})^0 * (1 - P_k^{D2})^0 * (1 - P_k^{D3})^1 * (1 - (1/2) * P_k^{D3})^1]
\end{aligned}
\tag{4.5}
$$

4.2.2.3 5mph Taxi Speed. At this slow taxi speed the majority of incoming rounds strike while the aircraft is on the move. Sixteen salvos arrive after the aircraft first moves from its initial position. This yields a probability of killing the aircraft of

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^2 * (1 - P_k^{A2})^2 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^3 \\
&\quad * (1 - P_k^{C2})^2 * (1 - P_k^{C3})^3 * (1 - P_k^{D1})^3 * (1 - P_k^{D2})^3 \\
&\quad * (1 - P_k^{D3})^2] + (1/2) * [1 - (1 - P_k^{B1})^2 * (1 - P_k^{B2})^2 \\
&\quad * (1 - P_k^{B3})^1 * (1 - P_k^{C1})^3 * (1 - P_k^{C2})^3 \\
&\quad * (1 - P_k^{C3})^4 * (1 - P_k^{D1})^4 * (1 - P_k^{D2})^3 * (1 - P_k^{D3})^3]
\end{aligned} \tag{4.6}
$$

The results for attack A are given in Figure 4.3. Attack II results are in Figure 4.4.

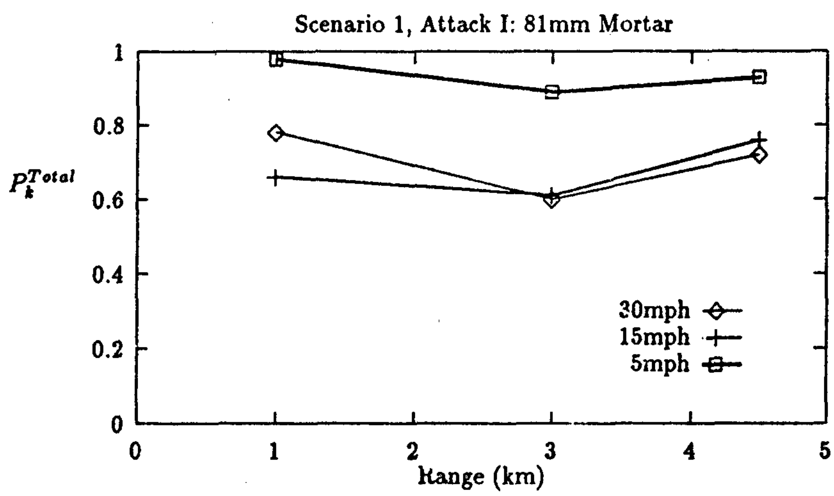


Figure 4.3. Effects of taxi speed on probability of kill with the 81mm Mortar. Attack I.

4.2.3 4.2in Mortar. The 4.2in heavy mortar can fire a maximum of eighteen rounds of high explosive shells for minute and a further nine the next minute before it must stop to let the barrel cool. Initially, this mortar fires a round every $3\frac{1}{3}$ seconds. During the second minute, the firing interval increases to $6\frac{2}{3}$ seconds.

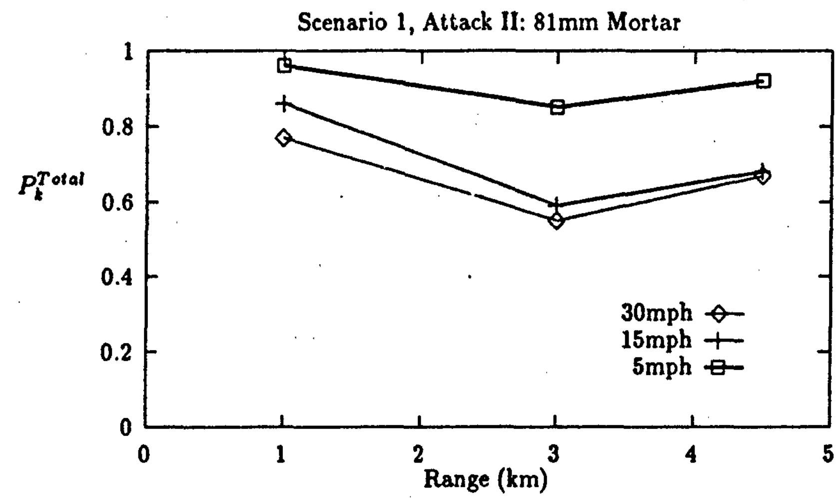


Figure 4.4. Effects of taxi speed on probability of kill with the 81mm Mortar. Attack II.

4.2.3.1 30mph Taxi Speed. At 30mph the aircraft can clear the danger area with only three shells or less falling between the time the aircraft begins moving and the time the aircraft is clear. The probability of kill is therefore

$$\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^1 * (1 - P_k^{A2})^1 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^1 \\
&\quad * (1 - P_k^{C2})^0 * (1 - P_k^{C3})^1 * (1 - P_k^{D1})^0 * (1 - P_k^{D2})^0 \\
&\quad * (1 - P_k^{D3})^0] + (1/2) * [1 - (1 - P_k^{B1})^1 * (1 - P_k^{B2})^1 * (1 - P_k^{B3})^1 \\
&\quad * (1 - P_k^{C1})^0 * (1 - P_k^{C2})^0 * (1 - P_k^{C3})^0 * (1 - P_k^{D1})^1 \\
&\quad * (1 - P_k^{D2})^0 * (1 - P_k^{D3})^1 * (1 - (1/2) * P_k^{D2})^1]
\end{aligned} \qquad (4.7)$$

4.2.3.2 15mph Taxi Speed. Decreasing the taxi speed only increases the number of rounds the aircraft encounters by one or two depending on the initial position of the aircraft. The kill probability is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^1 * (1 - P_k^{A2})^1 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^0 \\
&* (1 - P_k^{C2})^1 * (1 - P_k^{C3})^1 * (1 - P_k^{D1})^1 * (1 - P_k^{D2})^0 * (1 - P_k^{D3})^0] \quad (4.8) \\
&+ (1/2) * [1 - (1 - P_k^{B1})^1 * (1 - P_k^{B2})^1 * (1 - P_k^{B3})^1 * (1 - P_k^{C1})^1 \\
&* (1 - P_k^{C2})^1 * (1 - P_k^{C3})^0 * (1 - P_k^{D1})^1 * (1 - P_k^{D2})^0 \\
&* (1 - P_k^{D3})^0 * (1 - (1/2) * P_k^{D2})^1]
\end{aligned}
$$

4.2.3.3 5mph Taxi Speed. When the taxi speed is further reduced to 5mph, the number of rounds that the aircraft encounters before it is clear rises significantly. Still, the aircraft is clear before the second minute of firing commences. The probability that the aircraft is killed is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^{A1})^1 * (1 - P_k^{A2})^1 * (1 - P_k^{A3})^1 * (1 - P_k^{C1})^2 \\
&* (1 - P_k^{C2})^2 * (1 - P_k^{C3})^2 * (1 - P_k^{D1})^2 * (1 - P_k^{D2})^1 \quad (4.9) \\
&* (1 - P_k^{D3})^2 * (1 - (1/2) * P_k^{D2})^1] + (1/2) * [1 - (1 - P_k^{B1})^1 * (1 - P_k^{B2})^1 \\
&* (1 - P_k^{B3})^1 * (1 - P_k^{C1})^2 * (1 - P_k^{C2})^2 * (1 - P_k^{C3})^2 \\
&* (1 - P_k^{D1})^3 * (1 - P_k^{D2})^2 * (1 - P_k^{D3})^1 * (1 - (1/2) * P_k^{D3})^1]
\end{aligned}
$$

The results for attack A are given in Figure 4.5. Attack II results are in Figure 4.6.

4.2.4 105mm Howitzer. The 105mm howitzer (M102) fires at maximum rate of ten rounds per minute (RPM). Therefore a salvo arrives every six seconds. We compute the overall probability of an aircraft kill for each taxi speed then present the results.

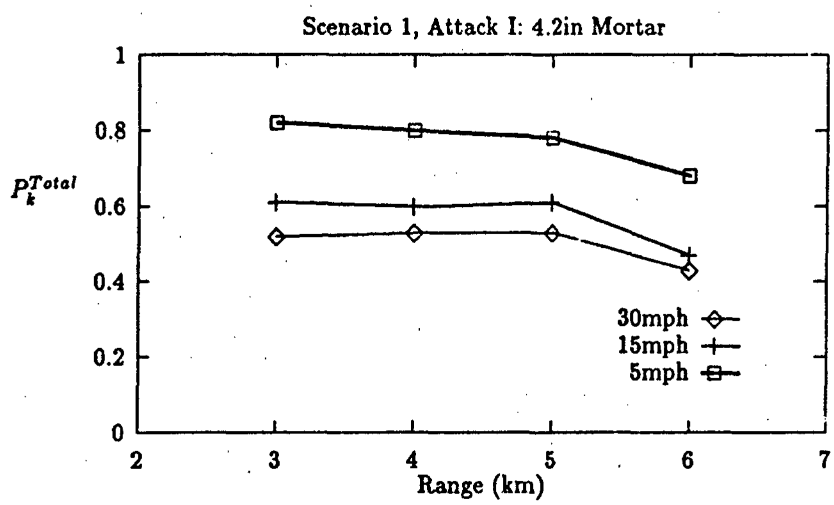


Figure 4.5. Effects of taxi speed on probability of kill with the 4.2in Mortar. Attack I.

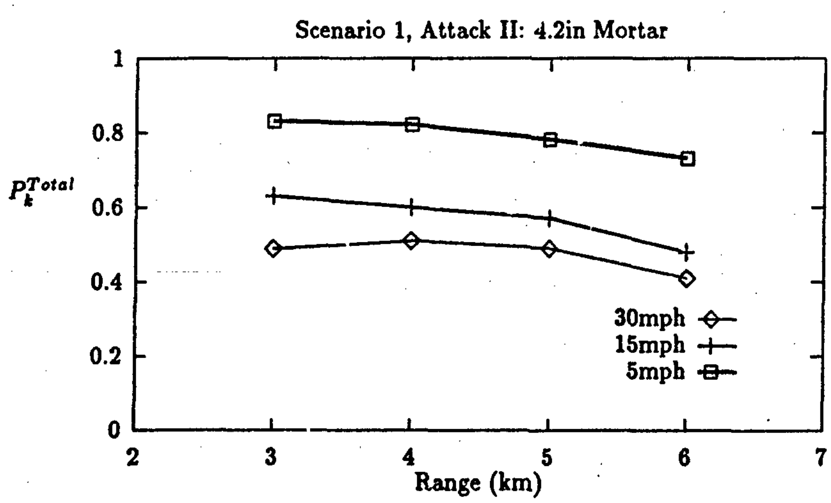


Figure 4.6. Effects of taxi speed on probability of kill with the 4.2in Mortar. Attack II.

4.2.4.1 30mph Taxi Speed. Two salvos fall when the aircraft is in the off-loading area and two salvos fall with the aircraft is on the taxiway. Because of the very fast taxi speed it clears the lethal area of the attack before the fourth salvo falls. Thus, the overall kill probability is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^2 * (1 - P_k^C)^2 * (1 - P_k^D)^0] \\ &+ (1/2) * [1 - (1 - P_k^B)^2 * (1 - P_k^C)^1 * (1 - P_k^D)^1] \end{aligned} \tag{4.10}$$

4.2.4.2 15mph Taxi Speed. Again, two salvos fall while the aircraft is in the off-loading area. With the slower taxi speed the aircraft is still in the area of the incoming rounds for three salvos. When the aircraft is conditioned upon being in Position A initially, the aircraft is approximately twenty meters outside the outer MPI on that side. This is a case where the aircraft is in Position D with shells falling on only one side, therefore the P_k^D is halved. The overall kill probability is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^2 * (1 - P_k^C)^2 * (1 - (1/2)P_k^D)^1] \\ &+ (1/2) * [1 - (1 - P_k^B)^2 * (1 - P_k^C)^3 * (1 - P_k^D)^0] \end{aligned} \tag{4.11}$$

4.2.4.3 5mph Taxi Speed. The first two salvos find the aircraft in the off-loading area. The extremely slow taxi speed means that the aircraft is in the lethal area of the sheaf during seven salvos when initially in Position A and eight salvos when initially in Position B. The extra salvo effects the second conditional probability because of the extra twenty meters the aircraft must taxi. The probability of a kill is

$$P_k^{Total} = (1/2) * [1 - (1 - P_k^A)^2 * (1 - P_k^C)^5 * (1 - P_k^D)^2] + (1/2) * [1 - (1 - P_k^B)^2 * (1 - P_k^C)^3 * (1 - P_k^D)^5] \quad (4.12)$$

The combined results of the three different taxi speeds are presented in Figure 4.7. Using the data for the MPIs falling between the runway and taxiway, equivalent results are in Figure 4.8.

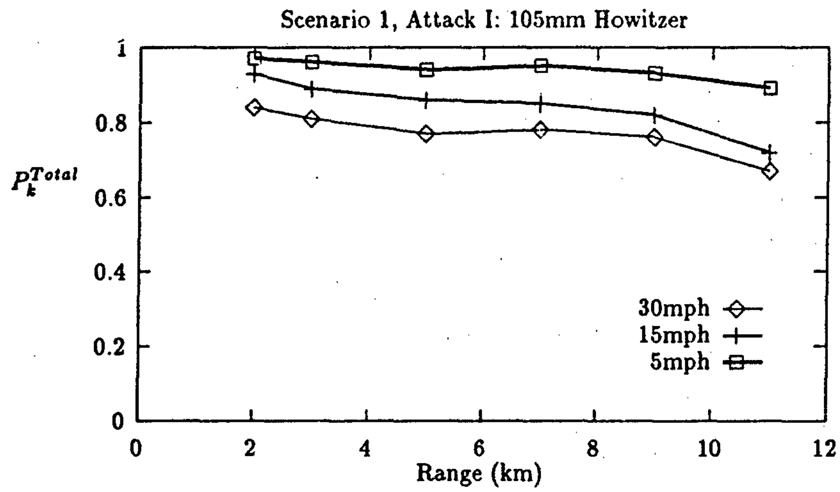


Figure 4.7. Effects of taxi speed on probability of kill with the 105mm Howitzer. Attack I.

4.2.5 155mm Howitzer. The 155mm self-propelled howitzer (M109) fires at a rate of three RPM. At this rate a salvo arrives every twenty seconds. Using the three taxi speeds as above we get the following kill probabilities.

4.2.5.1 30mph Taxi Speed. The attack again opens with the aircraft in the off-loading area. The rapid ground travel of the aircraft and the slow rate of

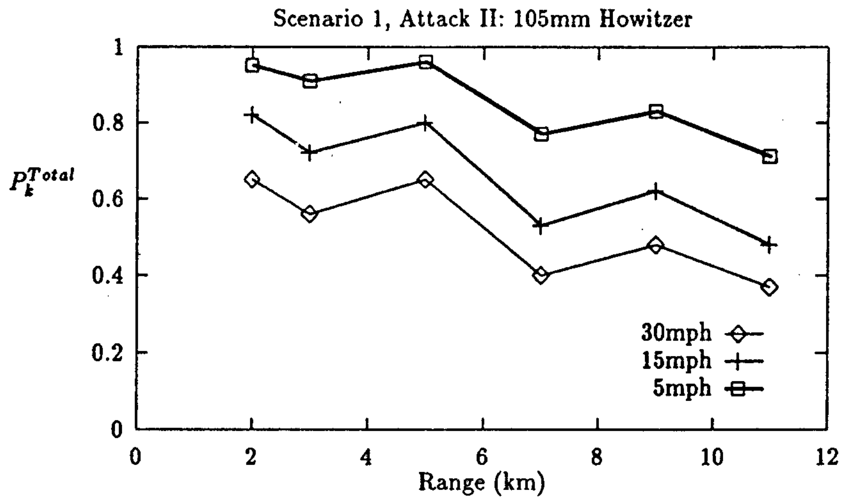


Figure 4.8. Effects of taxi speed on probability of kill with the 105mm Howitzer. Attack II.

fire mean that the aircraft is in the lethal area of fire only during the first two salvos. Therefore the probability of kill is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^1 * (1 - P_k^C)^1 * (1 - P_k^D)^0] \\ &+ (1/2) * [1 - (1 - P_k^B)^1 * (1 - P_k^C)^0 * (1 - P_k^D)^1] \end{aligned} \tag{4.13}$$

4.2.5.2 15mph Taxi Speed. At 15mph the aircraft lingers slightly longer on the taxiway but is still in the lethal area for only the first two salvos. The probability of a kill is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^1 * (1 - P_k^C)^0 * (1 - P_k^D)^1] \\ &+ (1/2) * [1 - (1 - P_k^B)^1 * (1 - P_k^C)^1 * (1 - P_k^D)^0] \end{aligned} \tag{4.14}$$

4.2.5.3 5mph Taxi Speed. At 5mph the aircraft is now on the taxiway for over one and one half minutes before clear of the area of attack. At the time of the fourth salvo the aircraft is at the outer boundary of the zone of fire when starting from Position A. It is approximately twenty meters from the center of an MPI but with an MPI on only one side. As above, the probability of kill in this position is only half that of position D. When starting in Position B, the aircraft is directly under the outer MPI when the fourth salvo falls. The overall kill probability at 5mph is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^1 * (1 - P_k^C)^0 * (1 - P_k^D)^2 \\ &* (1 - (1/2)P_k^D)^1] + (1/2) * [1 - (1 - P_k^B)^2 * (1 - P_k^C)^3 * (1 - P_k^D)^0] \end{aligned} \tag{4.15}$$

The combined results of the three different taxi speeds for the 155mm howitzer are presented in Figure 4.9. Centering the attack between the runway and the taxiway yields the results in Figure 4.10.

4.2.6 175mm Gun and 8in Howitzer. Both the 8in howitzer and the 175mm gun fire at a rate of two rounds per minute. The same rate of fire ensures that the overall probability of kill *equations* are the same. They are presented here and are followed by the individual numerical results in their respective charts.

4.2.6.1 30mph Taxi Speed. With a 30mph taxi speed the aircraft is well clear of the danger area by the time the second round falls, thirty seconds later. Therefore the probability of a kill is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^1 * (1 - P_k^C)^0 * (1 - P_k^D)^0] \\ &+ (1/2) * [1 - (1 - P_k^B)^1 * (1 - P_k^C)^0 * (1 - P_k^D)^0] \end{aligned} \tag{4.16}$$

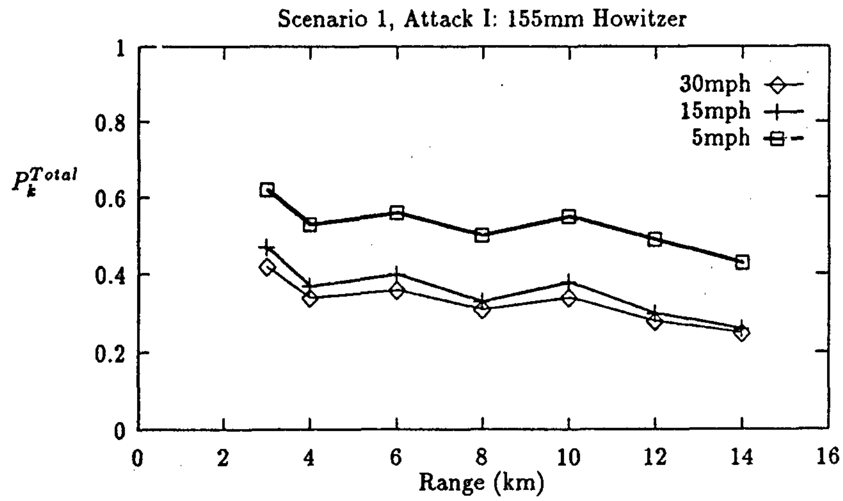


Figure 4.9. Effects of taxi speed on probability of kill with the 155mm Howitzer. Attack I.

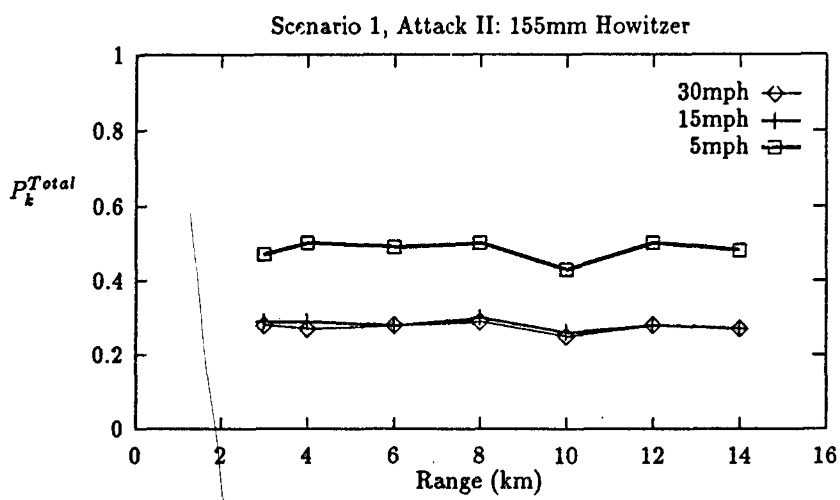


Figure 4.10. Effects of taxi speed on probability of kill with the 155mm Howitzer. Attack II.

4.2.6.2 15mph Taxi Speed. With a 15mph maximum taxi speed the aircraft is caught on the taxiway when the second salvo arrives. The overall kill probability is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^1 * (1 - P_k^C)^0 * (1 - P_k^D)^1] \\ &+ (1/2) * [1 - (1 - P_k^B)^1 * (1 - P_k^C)^1 * (1 - P_k^D)^0] \end{aligned} \tag{4.17}$$

4.2.6.3 5mph Taxi Speed. The aircraft clears the area by the fourth salvo, ninety seconds after the first salvo arrived. The second and third salvo catches the aircraft in on the taxiway. The overall probability of a kill is

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^1 * (1 - P_k^C)^2 * (1 - P_k^D)^0] \\ &+ (1/2) * [1 - (1 - P_k^B)^1 * (1 - P_k^C)^0 * (1 - P_k^D)^2] \end{aligned} \tag{4.18}$$

The results for the 175mm howitzer are given in Figure 4.11 and in Figure 4.12 for the attack centered in the off-loading area and the area between the taxiway and runway, respectively. The results of the 8in howitzer are in Figure 4.13 and in Figure 4.14. Again, the first figure contains the results when the attack is centered in the off-loading area and the second figure covers the attack when centered between the runway and taxiway.

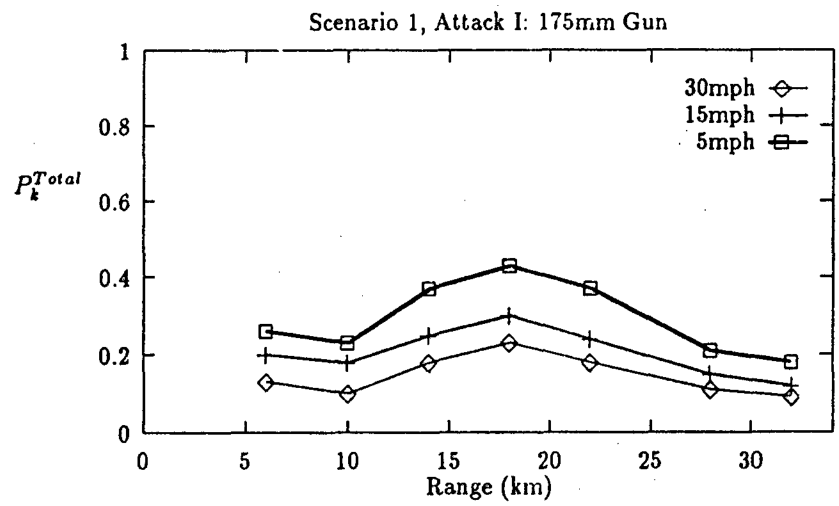


Figure 4.11. Effects of taxi speed on probability of kill with the 175mm Howitzer. Attack I.

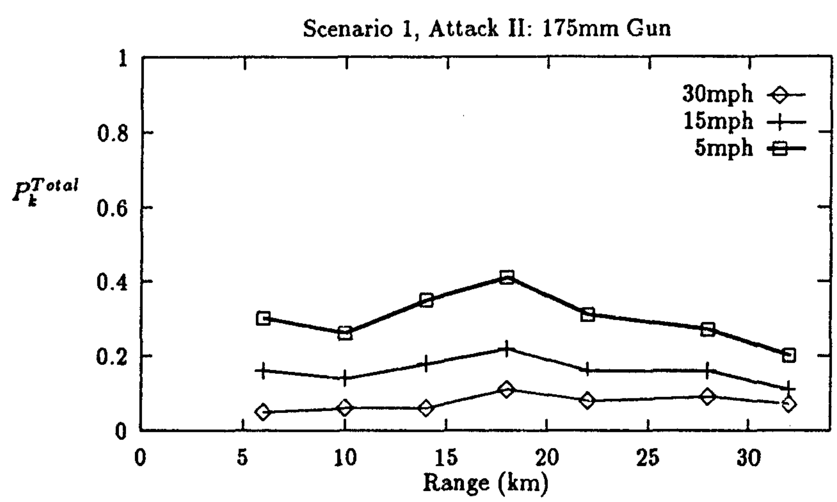


Figure 4.12. Effects of taxi speed on probability of kill with the 175mm Howitzer. Attack II.

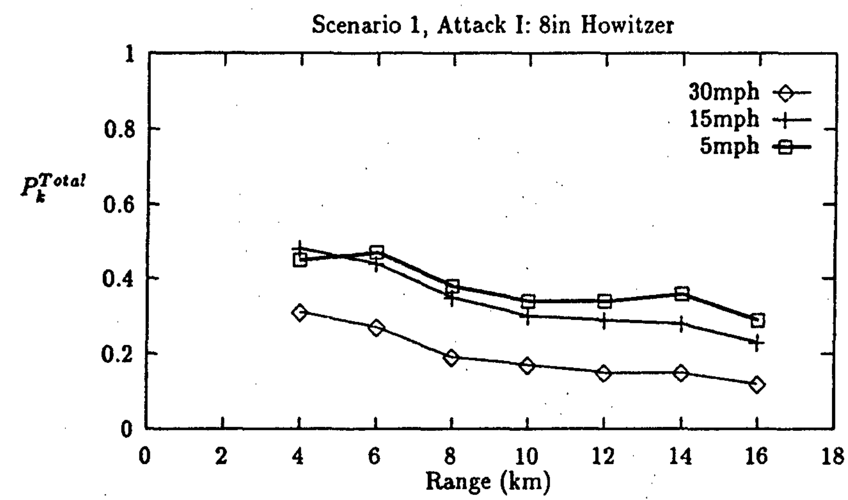


Figure 4.13. Effects of taxi speed on probability of kill with the 8in Howitzer. Attack I.

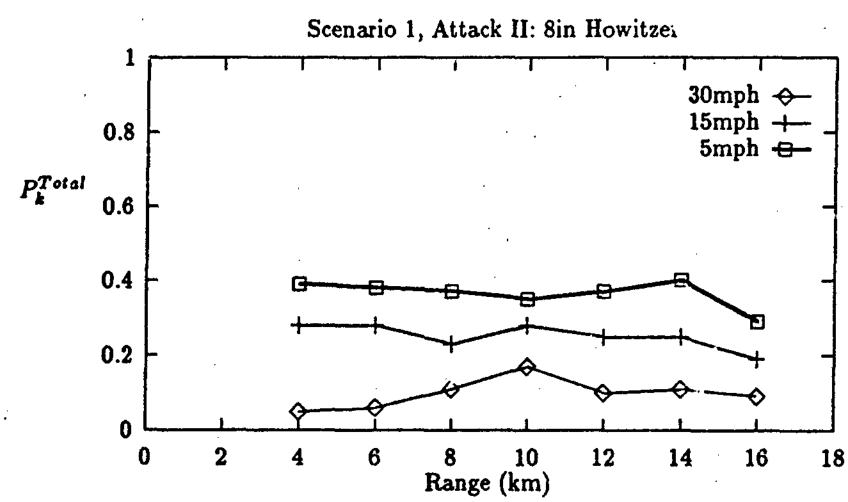


Figure 4.14. Effects of taxi speed on probability of kill with the 8in Howitzer. Attack II.

4.3 Scenario 2

In the second scenario, the time to initiate aircraft taxi is varied. A maximum taxi speed of fifteen miles-per-hour is used throughout. The equations used are very similar to those in Scenario 1, the difference being the increase in the exponent corresponding to the initial position of the aircraft. The delay times used are one, three, and five minutes. Five minutes is used as the upper amount of delay because an attack of this kind is not expected to last longer than that. Obviously, increasing the time the aircraft is sitting still during the attack decreases its probability of survival. This scenario instead focuses on how time on the ground and accuracy of the attack interact to affect aircraft survivability. Attacks by mortars were left out of this scenario because of their limited duration of fire.

4.3.1 105mm Howitzer. The following three equations are based upon the equation for P_k^{Total} used above for the 105mm Howitzer when maximum taxi speed is fifteen miles-per-hour.

4.3.1.1 One Minute Delay. The time before first aircraft movement is one minute starting from the time the first salvo arrives. The overall kill probability is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^{11} * (1 - P_k^C)^2 * (1 - (1/2)P_k^D)^1] \\
&\quad + (1/2) * [1 - (1 - P_k^B)^{11} * (1 - P_k^C)^3 * (1 - P_k^D)^0]
\end{aligned}
\tag{4.19}
$$

4.3.1.2 Three Minute Delay. The time before first aircraft movement is three minutes starting from the time the first salvo arrives. The overall probability of a kill is therefore

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^{31} * (1 - P_k^C)^2 * (1 - (1/2)P_k^D)^1] \qquad (4.20)\\
&+ (1/2) * [1 - (1 - P_k^B)^{31} * (1 - P_k^C)^3 * (1 - P_k^D)^0]
\end{aligned}
$$

4.3.1.3 Five Minute Delay. The time before first aircraft movement is five minutes starting from the time the first salvo arrives. Because the attack lasts for only five minutes, if the aircraft survives for five minutes it is able to taxi clear without the threat of further attack. The kill probability is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^{50} * (1 - P_k^C)^0 * (1 - (1/2)P_k^D)^0] \qquad (4.21)\\
&+ (1/2) * [1 - (1 - P_k^B)^{50} * (1 - P_k^C)^0 * (1 - P_k^D)^0]
\end{aligned}
$$

The results of both attacks and for the three delay times described above are presented in Figures 4.15 and 4.16

4.3.2 155mm Howitzer. As above, the basis for the following equations are the fifteen mile-per-hour maximum taxi speed equation from the first scenario.

4.3.2.1 One Minute Delay. The aircraft will initiate taxi one minute after the first salvo arrives. The total probability of killing the aircraft is

$$
\begin{aligned}
P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^4 * (1 - P_k^C)^0 * (1 - P_k^D)^1] \qquad (4.22)\\
&+ (1/2) * [1 - (1 - P_k^B)^4 * (1 - P_k^C)^1 * (1 - P_k^D)^0]
\end{aligned}
$$

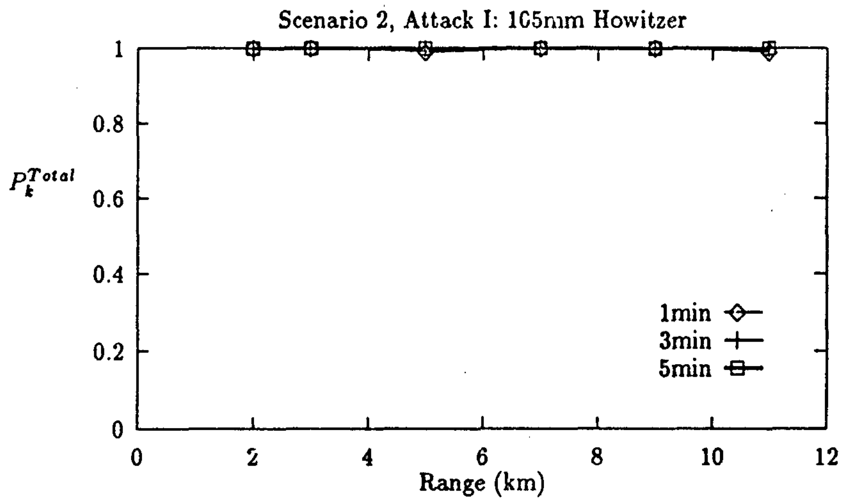


Figure 4.15. Effects of time to initiate taxi on probability of kill with the 105mm Howitzer. Attack I.

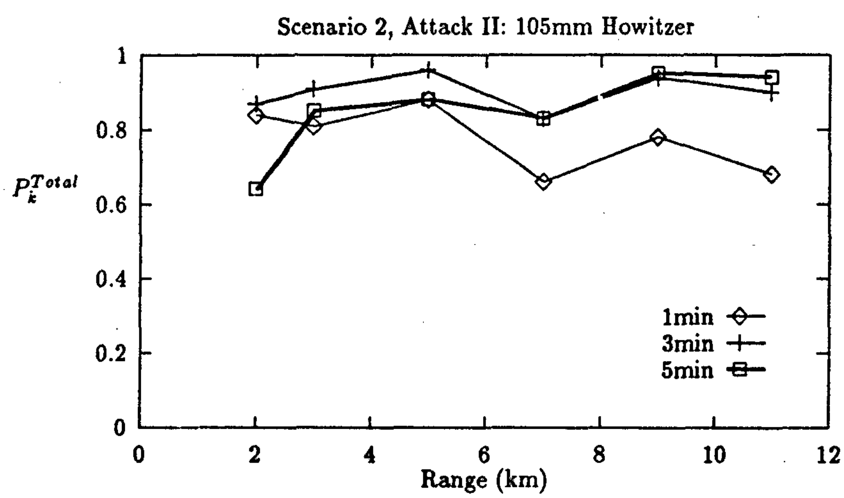


Figure 4.16. Effects of time to initiate taxi on probability of kill with the 105mm Howitzer. Attack II.

4.3.2.2 Three Minute Delay. A three minute delay until taxiing begins means that the first ten salvos have arrived when the aircraft first begins to move. The probability of killing the aircraft is therefore

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^{10} * (1 - P_k^C)^0 * (1 - P_k^D)^1] \\ &+ (1/2) * [1 - (1 - P_k^B)^{10} * (1 - P_k^C)^1 * (1 - P_k^D)^0] \end{aligned} \tag{4.23}$$

4.3.2.3 Five Minute Delay. The aircraft is immobile in the off-loading area for the duration of the attack. A surviving aircraft will taxi clear and depart the airfield without further salvos arriving. The probability of killing the aircraft is therefore

$$\begin{aligned} P_k^{Total} &= (1/2) * [1 - (1 - P_k^A)^{15} * (1 - P_k^C)^0 * (1 - P_k^D)^0] \\ &+ (1/2) * [1 - (1 - P_k^B)^{15} * (1 - P_k^C)^0 * (1 - P_k^D)^0] \end{aligned} \tag{4.24}$$

The results for Attack I are given in Figure 4.17. Attack II results are in Figure 4.18.

4.3.3 175mm Gun and 8in Howitzer. As in Scenario 1, because the firing rates of these two guns are equal, the equations governing P_k^{Total} are the same for the two weapons.

4.3.3.1 One Minute Delay. With a one minute delay, the aircraft remains in the off-loading area for the second and third salvos, the rest of the equation remains unchanged. The probability of a kill is

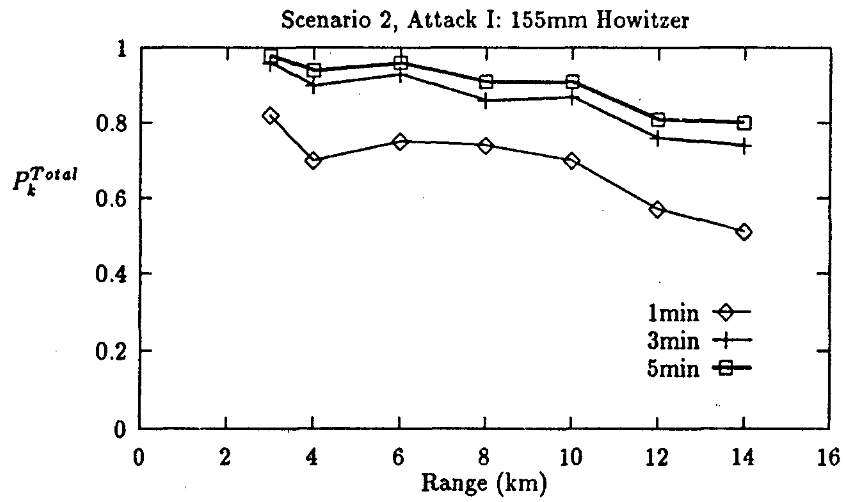


Figure 4.17. Effects of time to initiate taxi on probability of kill with the 155mm Howitzer. Attack I.

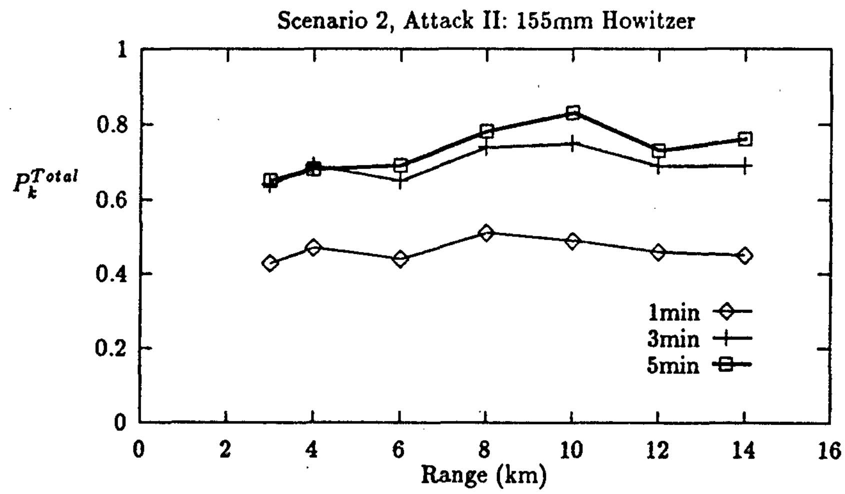


Figure 4.18. Effects of time to initiate taxi on probability of kill with the 155mm Howitzer. Attack II.

$$P_k^{Total} = (1/2) * [1 - (1 - P_k^A)^3 * (1 - P_k^C)^0 * (1 - P_k^D)^1] + (1/2) * [1 - (1 - P_k^B)^3 * (1 - P_k^C)^1 * (1 - P_k^D)^0] \tag{4.25}$$

4.3.3.2 Three Minute Delay. A three minute delay to initiate an escape from the airfield means the aircraft still faces destruction during the time it takes to clear the area of the attack. The probability of killing an aircraft is therefore

$$P_k^{Total} = (1/2) * [1 - (1 - P_k^A)^7 * (1 - P_k^C)^0 * (1 - P_k^D)^1] + (1/2) * [1 - (1 - P_k^B)^7 * (1 - P_k^C)^1 * (1 - P_k^D)^0] \tag{4.26}$$

4.3.3.3 Five Minute Delay. When delayed five minutes before movement, the attack is over before the aircraft leaves the off-loading area. This gives an overall probability of kill of

$$P_k^{Total} = (1/2) * [1 - (1 - P_k^A)^{10} * (1 - P_k^C)^0 * (1 - P_k^D)^0] + (1/2) * [1 - (1 - P_k^B)^{10} * (1 - P_k^C)^0 * (1 - P_k^D)^0] \tag{4.27}$$

The results for the 175mm howitzer are given in Figure 4.19 and in Figure 4.20, for the attack centered in the off-loading area and the area between the taxiway and runway, respectively. The results of the 8in howitzer are shown in Figure 4.21 and in Figure 4.22. Again, the first figure contains the results when for Attack I and the second figure covers the results of Attack II.

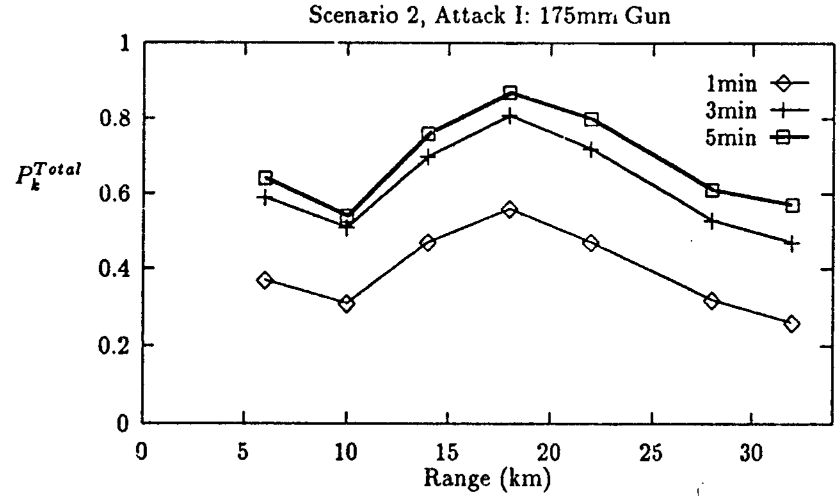


Figure 4.19. Effects of time to initiate taxi on probability of kill with the 175mm Howitzer. Attack I.

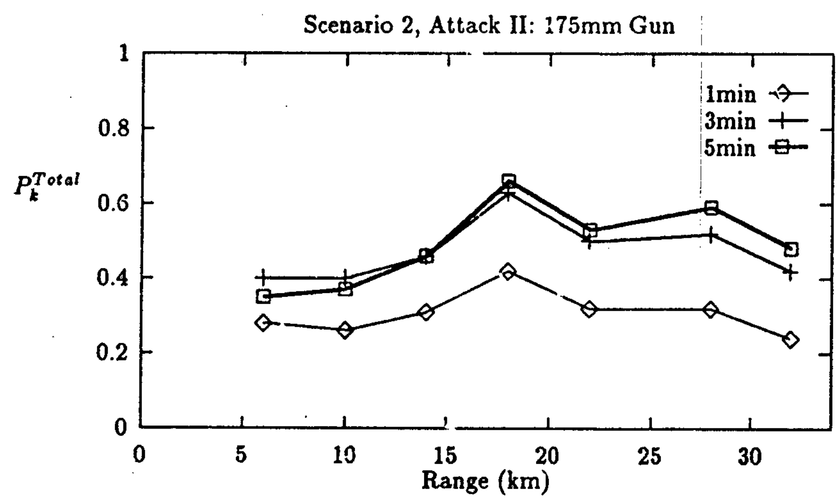


Figure 4.20. Effects of time to initiate taxi on probability of kill with the 175mm Howitzer. Attack II.

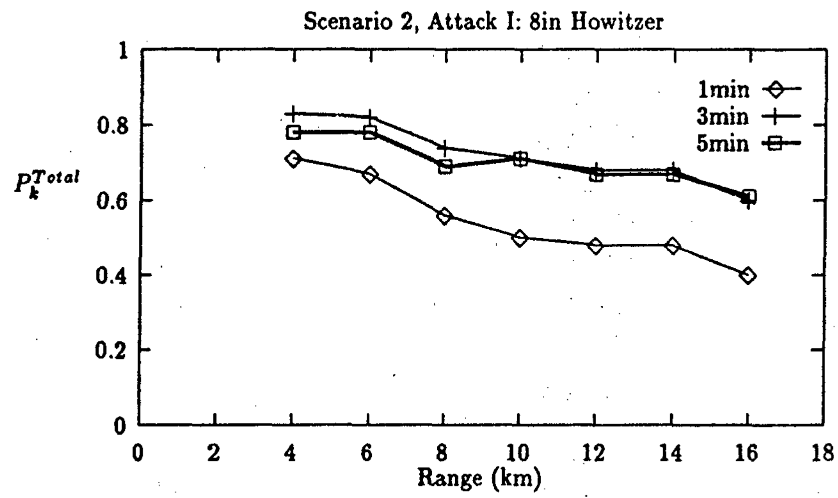


Figure 4.21. Effects of time to initiate taxi on probability of kill with the 8in Howitzer. Attack I.

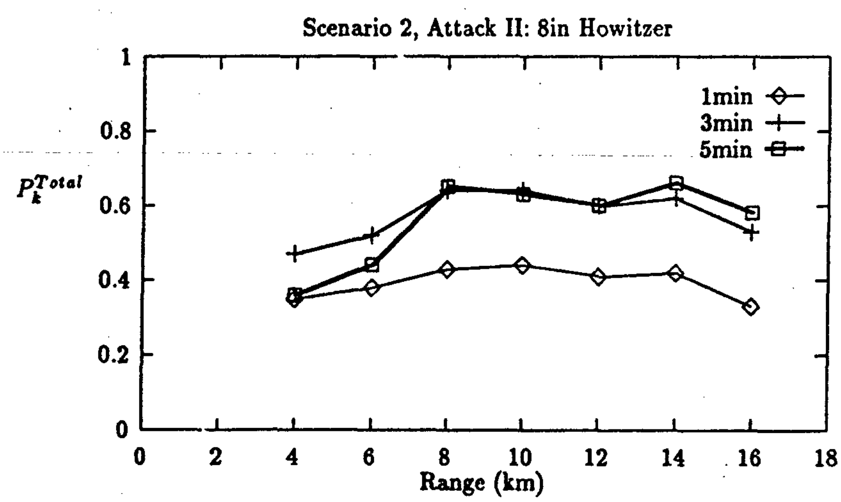


Figure 4.22. Effects of time to initiate taxi on probability of kill with the 8in Howitzer. Attack II.

4.4 Scenario 3

This section examines the increase in amount of time an airlifter would be grounded due to an attack on the runway. The data used to make these determinations comes from the 1992 Future Theater Airlift Study(15:A–30) done in support of GAMM. The number of attacks, the number of runway cuts per attack, and the mean time to repair all damage done in a single attack is shown in table 4.15.

Table 4.15. Scenario 3 data.

Attacks/Day	Cuts/Attack	Repair Time (hours)
1 or 2	2	4.5
1 or 2	10	4.5
1 or 2	2	10
1 or 2	10	10

The study leaves out several key points about the runway attack data. The most important points are the location of the cuts along the runway and whether their position is determined probabilistically or not. Their results yield the most critical loss in tons delivered as 4.1 percent when there are ten cuts per attack and ten hours needed for repair. This low loss in capability suggests that either the cuts are not equally spaced or that the number of airfields is so great that the temporary closing of some does not have much effect on tons delivered. The source of the data used was also absent from the study other than noting that it is from previous work on the project.

Here, we will make several assumptions to clarify the procedure followed and to simplify the computation. The first is that the cuts are equally spaced along the runway. This is the most effective way to prevent aircraft from taking off because equally spaced cuts will prevent a long portion of the runway from remaining operational with the cuts concentrated in other areas. This assumption is consistent with other assumptions made here in that the attack is the most lethal possible. The second assumption is that all cuts are made on the runway surface and no attacks

are wasted. Note that n equally spaced cuts divide the runway into $n + 1$ segments of equal length. It is also assumed that the taxiway is not suitable for takeoff.

Aircraft are considered to be in one of the following four categories:

- VSTOL aircraft can take off vertically and require almost no room to do so.
- SSTOL aircraft require 750 feet to perform a takeoff.
- STOL aircraft require 1500 feet to take off.
- Conventional Takeoff and Landing (CTOL) aircraft are equivalent to aircraft currently in service and require 3000 feet to take off.

As a baseline, thirty minutes is considered the longest amount of time an aircraft would normally spend on the ground with ground crews readily available to unload. This is consistent with assumptions made in the GAMM model.

Any cuts in the usable surface of a 3000 foot runway would ground a CTOL aircraft requiring that full distance to take off in (in a wartime environment the aircraft commander would probably reserve final judgement depending upon prevailing weather conditions and threat status). For the STOL aircraft described above, a minimum of two cuts would be required before the aircraft would be grounded. These two cuts would have to be positioned on either side of the runway midpoint to prevent takeoff. Equal spacing at 1000 and 2000 feet down the runway would accomplish this. Grounding a SSTOL aircraft requiring only one-quarter of a 3000 foot runway would require a minimum of five equally spaced cuts. Even a slight error in placing of the five cuts would leave enough space for the aircraft to escape since the aircraft needs only 150 feet more than would be available between the five cuts. The only way to ground a VSTOL aircraft is to damage the actual aircraft. The fact that the aircraft needs no runway to operate is what makes VSTOL aircraft so desirable (although beyond the scope of this work, the cargo limits of VSTOL or SSTOL aircraft might seriously degrade their relative merits).

In the case of one of the above situations, the vulnerability of the aircraft is now a function of the time to repair the runway to a state where the required length of runway is usable. Once again, information from the previous study is lacking and the repair times give no indication about the time required to repair a single cut in relation to several. We will therefore assume that the time to repair a single cut is an equal fraction of the time to repair all the cuts. That is, if the time to repair ten cuts is 4.5 hours, then the time to repair one cut is 0.45 hours. At this point a comparison can be made between the different types of aircraft as to how long they are grounded due to runway damage. The results are displayed in the following two tables. Results are grouped by the total time to repair all cuts made in the runway. In addition to the two and ten cuts per attack, data is given for eight and four cuts per attack.

Table 4.16. Time aircraft will be grounded based on a 10 hour repair time.

10 Hours to Repair All Cuts				
Aircraft Class	Number of Cuts Per Attack	Number of Cuts to be Repaired	Time to Repair One Cut	Time to Repair Necessary Cuts
VSTOL	10	0	1.0	0.0
	8	0	1.25	0.0
	4	0	2.5	0.0
	2	0	5.0	0.0
SSTOL	10	3	1	3.0
	8	2	1.25	2.5
	4	0	2.5	0.0
	2	0	5.0	0.0
STOL	10	6	1.0	6.0
	8	5	1.25	6.25
	4	2	2.5	5.0
	2	1	5.0	5.0
CTOL	10	10	1	10.0
	8	8	1.25	10.0
	4	4	2.5	10.0
	2	2	5.0	10.0

Table 4.17. Time aircraft will be grounded based on a 4.5 hour repair time.

4.5 Hours to Repair All Cuts				
Aircraft Class	Number of Cuts Per Attack	Number of Cuts to be Repaired	Time to Repair One Cut	Time to Repair Necessary Cuts
VSTOL	10	0	1.0	0.0
	8	0	1.25	0.0
	4	0	2.5	0.0
	2	0	5.0	0.0
SSTOL	10	3	1	1.35
	8	2	1.25	1.125
	4	0	2.5	0.0
	2	0	5.0	0.0
STOL	10	6	1.0	2.7
	8	5	1.25	2.813
	4	2	2.5	2.25
	2	1	5.0	2.25
CTOL	10	10	1	4.5
	8	8	1.25	4.5
	4	4	2.5	4.5
	2	2	5.0	4.5

4.5 *Observer-Directed Mortar Attacks*

As mentioned earlier, an observer greatly increases the chance of an attacker destroying an aircraft because the observer corrects the lay of fire based on direct observation. The effects of dispersion on accurate corrections are lessened because of the short time required to adjust the aim-point and the number of rounds required for a final fix on the target. Atmospheric conditions will change very little if at all during the attack, barrel wear is minimum with only a few rounds being fired, and barrel heating is minimal because of the time to adjust fire between rounds. Dispersion will still exist between rounds but since direct observation is used, corrections can be made if the majority of incoming rounds appear to be directed at a point other than the center of the aircraft. Also, since the observer will redirect the mortar fire after the initial aircraft is destroyed, the number of rounds fired at a particular target will be much fewer than when no information is immediately available.

Taking all these factors into account, we can develop some equations for the P_k^{Total} for this type of attack. It is assumed that the first and second rounds miss their target somewhat and that the subsequent rounds are centered (with a normal dispersion) on the aircraft. Using the four positions already defined in Chapter 3, we can use P_k^{B2} for the first two rounds, with the probability taken from Attack II. This gives a lateral displacement of twenty meters to the side of the aircraft and approximately thirty meters in front of or behind the aircraft. Following rounds will be centered on the aircraft, thus Position A in Attack I is the appropriate source of P_k's.

Thus for any mortar, the equation for the observer-directed attack is

$$P_k^{Total} = 1 - (1 - P_k^{B2})^2 * (1 - P_k^{A})^x \qquad (4.28)$$

where x is the number of rounds fired after the first two.

Assuming that the observer remains undetected, the number of rounds fired will be no more than the number required to destroy the aircraft. Once again, the speed of the attack precludes the aircraft escaping destruction even if taxi is initiated in a reasonable amount of time. Of course if the aircraft initiates taxiing immediately after the first round is fired it may survive. However, even a delay of ten seconds would give the mortar crew time to fire up to six rounds, four of them accurately placed. In this type of attack, aircraft survivability is minimal with escape possible only if departure is initiated before the attack begins. In general, an observer-directed attack is fatal to a parked aircraft.

4.6 Direct-Fire Weapons

The purpose of this section is to present some hit probabilities for several man-portable weapons which are capable of destroying a parked aircraft. These weapons include guided and unguided missiles, recoilless rifles, and fuel-air explosive launchers. Although these weapons are all designed for the ground battle environment, they would be very effective because of an aircraft's large volume of flammable fuels and its lack of armor.

Although the airbase will have a force of Security Police, as a minimum, many of these weapons are small enough to be concealed on one's person. Concealable weapons become a threat anytime operations occur near populated areas. This threat is very real when operating in enemy territory or when enemy forces are operating in close proximity to the airfield. The smaller, unguided weapons have ranges in the hundreds of meters and the larger, usually guided weapons, have ranges out to several kilometers.

Based on several different sources of JMEM data, Table 4.18 contains estimates for the probability of hitting a target, P_h. These estimates are extrapolated from the given data by comparing the relative size of a main battle tank to that of a large aircraft. The table gives hit probabilities based on the range to the target, the

direction of the attack (which changes the relative size of the target), and whether the aircraft is moving or not.

The four weapons are representative of most of the man-portable infantry weapons currently in use. The Light Anti-Tank Weapon or LAW represents various unguided missiles which might fire several different types of munition. High explosive is the most widespread ammunition for these weapons but fuel-air explosives, designed to damage by creating high overpressures, and shaped-charge weapons, designed to defeat thick armor, are also in use. The 90mm recoilless rifle represents unguided and unboosted weapons of large calibre. The recoilless rifle works on the principle that by venting the explosive gases through rear-ward facing ports, the recoil associated with firing the weapon can be nearly eliminated. This means that the weapon can be made much lighter and be fired from a light ground mount.

The Dragon is a one-man-portable medium anti-tank weapon. The missile is guided through a wire which links the missile to the launcher. The operator guides the missile simply by maintaining the target in the aiming reticle. The Tube launched, Optically tracked, Wire guided (TOW) missile represents heavy anti-tank weapons found in most military inventories. It is guided similarly to the Dragon and is designed to penetrate the thickest armor of an enemy's main battle tank.

The weapons included in the table represent over fifty years of infantry weapon development. The recoilless rifle was first used in the 1940s, the LAW was first developed in 1960, and the Dragon and TOW were both from the 1970s. All of these weapons are still used by the United States Army although sometimes in much more advanced forms. Regardless of modern improvements, the original models of these weapons are almost as accurate and have nearly the same range. These or similar weapons are probably possessed by every military establishment in the world, not to mention para-military forces and terrorist organizations. Their widespread dissemination, small size, and high lethality make this class of weapons a very significant threat.

Table 4.18. Probability of hitting a medium size transport with various infantry weapons.

Weapon	Range (m)	Target Face	Moving ?	p_h
LAW	100-250	Side-On	Y or N	1.0
	250-350	Side-On	Y or N	0.8
	100-200	Head or Tail	N	1.0
	200-350	Head or Tail	N	0.3
	100-200	Head or Tail	Y	0.9
	200-350	Head or Tail	Y	0.25
90mm Recoilless Rifle	100-400	Side-On	Y or N	1.0
	400-500	Side-On	Y or N	0.8
	100-200	Head or Tail	Y or N	1.0
	200-400	Head or Tail	Y or N	0.8
	400-500	Head or Tail	Y or N	0.5
Dragon	60-1000	Head or Tail	Y or N	1.0
TOW	500-3500	Head or Tail	Y or N	1.0

V. Conclusions and Recommendations

5.1 Inferences Based on Collected Data

The results of the research cover several areas of tactical airlifter design and use. Scenario 1 yields results sensitive to an airlifter's ground mobility. Scenario 2 considers the dwell time and time to off-load cargo. The third scenario deals with the aircraft's short field takeoff capability. All of the scenarios yield information on how the lethality of ground based weapons varies with type, range, and accuracy. Indirectly, the intelligence information available to enemy forces and other factors are also available. Each of these topics is covered in detail below.

5.1.1 Scenario 1. Results from this section show a marked increase in survivability (decrease in P_k^{Total}) when the taxi speed was increased from a maximum of five to fifteen miles per hour. This increase applies to every weapon examined except one. The exception occurred for the 8in Howitzer firing at a range of four kilometers in Attack I. This single anomaly (a three percent improvement in survivability with slower speed) can most likely be accounted for by the use of the dispersion rectangles. The small scale of the rectangles gives a slight loss in accuracy in the P_k^i. Disregarding this data point, this threefold increase in taxi speed yields clear benefits to an aircraft on the ground.

When the taxi speed is further increased to thirty miles per hour, the results are less definitive. For the most part the further increase in taxi speed did result in higher survivabilities but these were of a smaller magnitude than before. This decrease in magnitude of the change is certainly a result of the smaller change, only a twofold increase in taxi speed versus a threefold increase. There are two cases which contain anomalous data points. The 60mm and 81mm Mortars both show that at their shortest ranges, aircraft survivability is lower at the fifteen mile per hour taxi speed than at thirty miles per hour. In both cases this was true only

for Attack I. In order to discover if the four point analysis method was to blame for these anomalies, the multi-point method was also used at these points. The multi-point method yielded the same anomalous readings although the gap between the two readings was somewhat smaller. In the author's opinion, these results are merely representative of the fact that beyond fixed speeds and firing rates, aircraft will sometimes be directly under a falling shell and sometimes not. It is believed that this is the reason these two points do not concur with the results in other portions of the study.

When all factors are considered, the conclusion to be drawn from Scenario 1 is that increases in the aircraft's taxi speed will increase its chance of survival. This will be true for any aircraft when faced with conditions similar to those modelled in this study. These results are summarized in Figure 5.1. For each weapon type, the average probability of kill was found at each of the three taxi speeds examined in this scenario. For example, the average probability of a 105mm howitzer destroying an aircraft is the simple average of the kill probabilities at each of the ranges studied for this weapon. An average was found for each taxi speed that was examined.

5.1.2 Scenario 2. This scenario focused on the possibility of improving the survivability of aircraft by varying the time the aircraft required to initiate an escape. Initial taxiing was delayed from one, three, or five minutes with the maximum taxi speed held constant at fifteen miles per hour.

Not surprisingly, any delay in initiating the aircraft's movement decreased the aircraft's survivability as compared to Scenario 1 data (fifteen MPH maximum taxi speed). This was true for all of the weapons examined. This decrease in survivability was largest for Attack I where the attack was centered in the off-loading area. When the MPIs missed their intended aim-point and fell between the taxiway and runway, the decrease in survivability was not as drastic. For Attack II, the increased time waiting to taxi was not as lethal simply because the shells were landing farther away

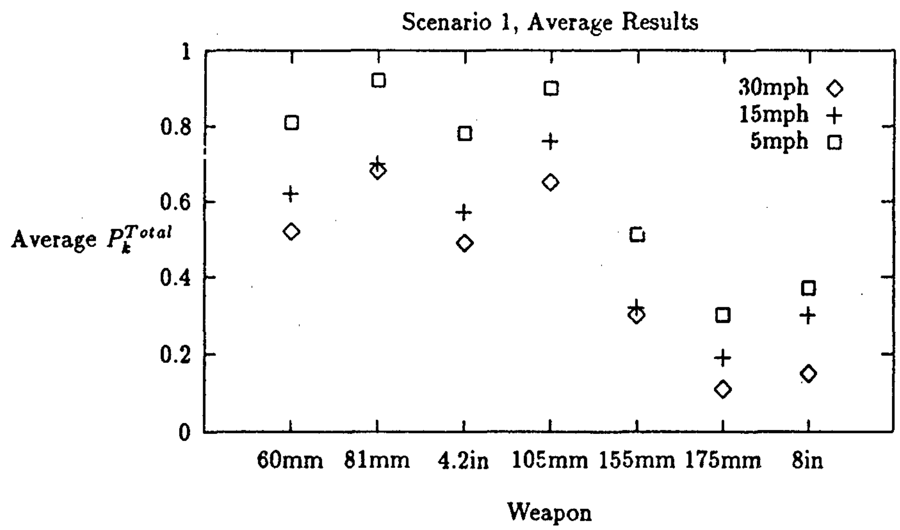


Figure 5.1. Average probability of kill by weapon type. Scenario 1.

than when Attack I conditions held. This led to findings that implied that increased waiting times increased survivability. This was especially true when the weapons fired from closer range. The reason for these results is that at close firing range, the potential spread of shells from each gun is very small. This small spread protects the aircraft in the off-loading area from potential damage while they remain there. When the aircraft taxi forward and then down the taxiway, they are much closer to the MPIs and therefore more vulnerable. When the weapons fired from longer ranges, the aircraft that waited for five minutes before taxiing (the full duration of the attack) consistently received higher P_ks. This is true because at the long ranges, the aircraft's survivability is less sensitive to the distance between the aircraft and the MPI. At only one data point was waiting five minutes more survivable than waiting one minute and there were no results showing that waiting three minutes was preferable to a wait of one minute.

Between the different weapons it was found that higher firing rates had a profound impact on the survivability of the aircraft. The 105mm howitzer, with a

firing rate of ten rounds per minute, achieved kill probabilities approaching unity in Attack I. The 155mm howitzer, firing at a rate of three RPM, was not as lethal as the 105mm. The 155mm however, was still significantly more lethal than 175mm or 8in artillery which fired at two RPM. When weapons had identical firing rates, the size of the munition (as measured by the lethal radius of the munition) determined the relative lethality. An aircraft attacked by a smaller calibre weapon was more likely to survive against a larger weapon firing with the same frequency.

The results from this scenario indicate that the rate of fire of an attacking weapon is a very important factor in determining its lethality. This result is corroborated by the results of Scenario 1 which indicated the same, although without complete agreement. Another, less intuitive conclusion, is that the ability to prepare the aircraft quickly for takeoff may not increase the survivability of the aircraft and may even decrease it. By decreasing the time required to prepare an aircraft to taxi, the aircraft spends less time in the area of the attack (if the aircraft is parked in the area under attack). The decreased preparation time is beneficial unless the aircraft is more vulnerable on the taxiway than in the off-loading area, in which case waiting in the off-loading area for the duration of the attack increases the aircraft's survivability. The factor of chance also plays a part in the aircraft's survivability. In some cases, the waiting time of the aircraft, the rate of fire of the attacking weapon, and the taxi speed of the aircraft all combine to put the aircraft in the wrong place at the wrong time. For example, these factors may combine to place an aircraft directly beneath an incoming munition in one case, and in another case the aircraft might be twenty meters away from the MPI. Further study of the results implies that unless the aircraft can be readied very quickly, no change in its survivability can be realized. In this study an attack lasts for a maximum of five minutes. Therefore, no advantage is gained by decreasing the time needed to initiate taxi, unless this time is reduced to below five minutes. This is not to say that reducing the time needed to off-load the aircraft is not advantageous. By reducing the time to off-load

the aircraft, less time is spent on the ground and the aircraft is less likely to be there when an attack occurs. Figure 5.2 gives averaged results of this scenario. The probability of destroying an aircraft is averaged for each weapon and at the three delay times used in this scenario. The data from the first scenario, where taxi speed is held to 15mph, is included in the data as well and is labeled "0 Wait".

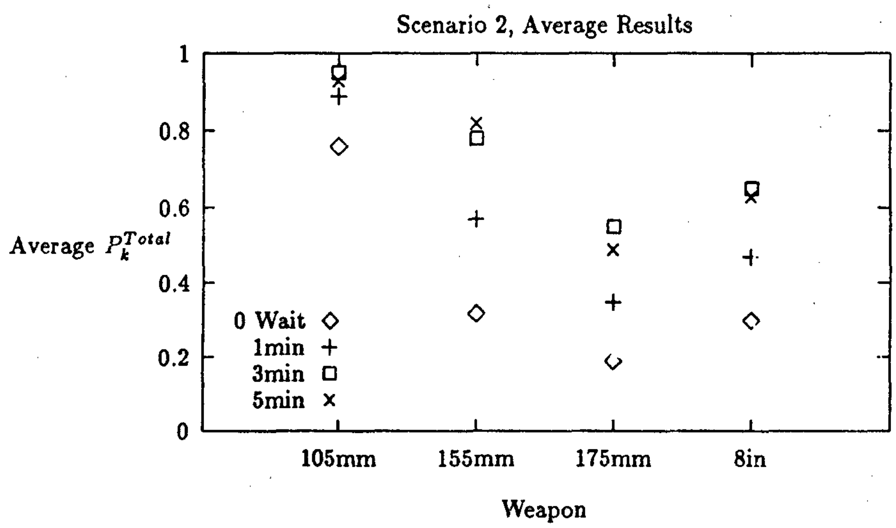


Figure 5.2. Average probability of kill by weapon type. Scenario 2.

5.1.3 Scenario 3. The purpose of Scenario 3 was to get a better understanding of how the airlifter's takeoff requirements affected its time on the ground. It is clear that the less (usable) runway required to take off, the less time the aircraft is grounded when a runway cutting attack takes place.

With the data that was used, it is clear that the VSTOL aircraft has a great advantage over SSTOL and that SSTOL has a great advantage over STOL and CTOL. The VSTOL aircraft's ability to take off without a runway makes it the clear winner in this scenario. This type of airlifter is only vulnerable for the time it needs to perform its off-load operations, regardless of the runway condition. Assuming thirty

minutes to land, off-load, and depart, a VSTOL aircraft is vulnerable to attack for about 2% of a twenty-four hour day regardless of the condition of the runway.

Using the data from Table 4.16 ,where it takes ten hours to repair all damage after an attack on the runway, we can make the following comparisons. The SSTOL, although affected by runway damage, still shows marked improvement over the STOL and CTOL. Since the SSTOL is unaffected when the number of runway cuts is below five (equally spaced on a 3000 foot runway) it is much more survivable in those cases. In the cases where runway repair operations must take place for the SSTOL to takeoff, it is generally only one-half as vulnerable as the STOL and one-fourth as vulnerable as the CTOL. With a three hour delay to repair the runway (assuming the attack occurred after the aircraft is off-loaded) a SSTOL aircraft is vulnerable approximately 15% of a day. This makes it seven times more vulnerable to attack than the VSTOL aircraft. A STOL aircraft, with a six hour delay caused by runway repair operations, is vulnerable 27% of a day A CTOL aircraft, requiring ten hours of repair work, is on the ground for 44% of a day each time the aircraft is caught on the ground when the runway is sufficiently damaged.

These numbers simply assess the time the aircraft is on the ground. The comparison between time on the ground for the different aircraft is based on the assumption that an attack can occur at any time of the day or night. The probability of an aircraft being on the ground during an attack is simply a ratio of the time it spends on the ground, over twenty-four. It is clear that the ability to depart an area of potential attack greatly increases any *one* aircraft's survivability. This compounds the benefits though, because losing an airlifter affects the capacity of the entire airlift operation for the length of the campaign.

5.1.4 The Threat of Attack by Infantry Weapons. The widespread availability of small, high-explosive projectile launchers makes them a credible threat any time an aircraft is on the ground. The primary defense against these easily con-

cealed weapons is an established defense perimeter. The 4000 meter perimeter that Air Force Security Police use as standard is sufficient to prevent almost all man-portable weapons from being used effectively against parked aircraft. During the early stages of an operation using a forward base, this perimeter can be threatened by a lack of man power and unfamiliarity with the area to be defended. Insuring that security forces arrive at the outset of the operation will do much to alleviate any problems. Whether this perimeter can be kept secure is a matter of conjecture, but additional security forces would insure that these weapons are not brought to bear against aircraft on the ground.

5.1.5 Overall Trends in Data. There were several trends that permeated all parts of this study. Possibly the most important factor in an attack of this kind is the enemy's knowledge of the target area. In Attack II, a bias of fifty meters is introduced to see how lethality decreases as accuracy decreases. Even with a bias as small as was used here (relative to ranges of up to thirty-two kilometers), the lethality projections declined by up to fifty percent. It must also be remembered that the center of Attack II was only a few meters from the taxiway. If the bias in Attack II had been fifty meters on the other side of the off-loading area, lethality projections would have decreased even further. This factor is less critical in the case of a previously operating airfield because its location is probably well known. However, in the case of an austere field (which may only be a stretch of highway or farmers field), locating the target with precision is much more difficult. For these reasons, the ability of the enemy to monitor airfield operations must be minimized in order to maximize aircraft survivability.

Less quantifiable but equally important to a measure of survivability is an assessment of the skill of the attackers. In this study, all factors pertaining to performance of the attacker was maximized. These factors include accurate laying of fire, firing at the maximum rate allowed by weapon specifications, and synchronized firing and spacing of MPIs between the different weapons. Of these factors, two

are critical to the lethality of the attack. The accurate laying of fire means that the weapon crew has the ability to accurately interpret reports of where the targets are located, and then translate these reports into firing coordinates. Being able to operate efficiently as a crew is key to getting the most out of a weapon. It was seen that the most lethal weapons, all other things being equal, are the ones that fire the most rapidly. Therefore, an inexperienced crew unable to use their weapon to its designed limits, degrades the lethality of their attack.

5.2 Recommendations for Further Research

This study was performed to assess the function determining probability of survival on the ground that is used by GAMM. As such there are many areas where in depth analysis was substituted for completeness. Therefore, there are many possible extensions to this work.

The first work done to improve this study should be to build a computer program which can perform all the needed computations. A computer model or simulation would have more flexibility to answer questions and perform sensitivity analysis. Many simplifications and assumptions were made in the formulation of the method used. One of the assumptions was that airlifters were never stranded on the ground due to equipment failure resulting from use. A true representation of ground operations includes aircraft that are grounded awaiting maintenance or arrival of parts. Since this study focuses on forward bases where aircraft support services are minimal, reliability and maintainability will influence the number of aircraft on the ground at the time of the attack. Also, questions arise as to whether a grounded aircraft should be counted as such when the MOG is reached. For example, does the danger of having an additional, immobile, aircraft on the ground outweigh the need to use the airfield at its highest capacity? Another simplification was that cargo was considered to be immediately removed from the area by ground support personnel. This, combined with the fact that combat offload procedures were not

modelled, leaves open another important area to be studied. Studies are currently underway to develop an autonomous cargo handling system. It would be worthwhile to study the use of this equipment in an analysis of how cargo handling affects an aircraft's time on the ground. Autonomous cargo handling might also be studied to see whether it is fast enough to increase the survivability of an aircraft that is under fire, as discussed above. The availability of this equipment might also influence the prevalence of combat off-load techniques. Combat off-load of cargo is limited by the availability of cargo handling equipment because the cargo is off-loaded directly onto the runway, taxiway, or other area where aircraft can taxi. The disadvantage to this technique is that areas where an aircraft can taxi are limited and the cargo handling capacity of ground forces is equally limited. Thus, extended use of combat off-load of cargo tends to clog up areas vital to aircraft operations such as taxiways and even runways.

Significant contribution could also be make by integrating the method and results of this study with the very high level engineering studies. The engineering studies that were reviewed in Chapter 2 give detailed survival probabilities based upon a single shot. Combining this information with the probability of the aircraft being hit that this study calculated (the probability of being hit equating to the probability of being destroyed in this study) would more accurately depict an aircraft's probability of survival.

Another direction for work further is the integration of the results of this and future studies with the functions that drive GAMM and other tools. To assess the impact of changes in airlifter design, the aircraft must be analyzed within the context of its entire mission. Therefore the results from work done without the use of GAMM must be integrated to understand how the probability of aircraft survival on the ground is influenced. Survivability on the ground impacts the operational effectiveness of the theater airlift system and the cost-effectiveness of both the airlift system and the aircraft themselves.

Appendix A. Dispersion Rectangles

This appendix contains a complete set of the dispersion rectangles used in this study to measure kill probabilities of indirect fire weapons. All rectangles are equal in scale. The direction of fire is always parallel to the long axis of the rectangle as range dispersion is always equal to or greater than lateral dispersion. The rectangles are grouped by weapon, mortar and then artillery. Each weapon group is arranged in increasing range to target.

The dimensions of probable error are given in firing tables that are published for every indirect fire weapon that the Army uses. The information in these tables concerning dispersion is based on test firings conducted at Aberdeen Proving Ground, Maryland(6)[3]. Firing tables for mortars were available and dispersion rectangles for the three mortar sizes were made based on dimensions given(6)(7)(8). The dispersion varies based on firing angle and the amount of propellent used. The dimensions used in the study were the smallest of those given.

Firing tables for artillery were not readily available but the JMEM Basic Effectiveness Manuals(12) gave dispersion dimensions for artillery at the ranges used in this study. The manual did not give explanation as to where the data came from but it most likely also came from test firings at Aberdeen.

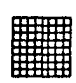


Figure A.1. Dispersion rectangle for 60mm mortar, range = 100m.

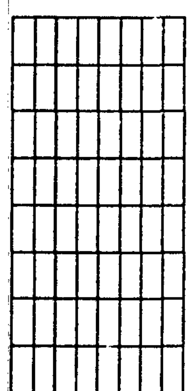


Figure A.2. Dispersion rectangle for 60mm mortar, range = 1000m.

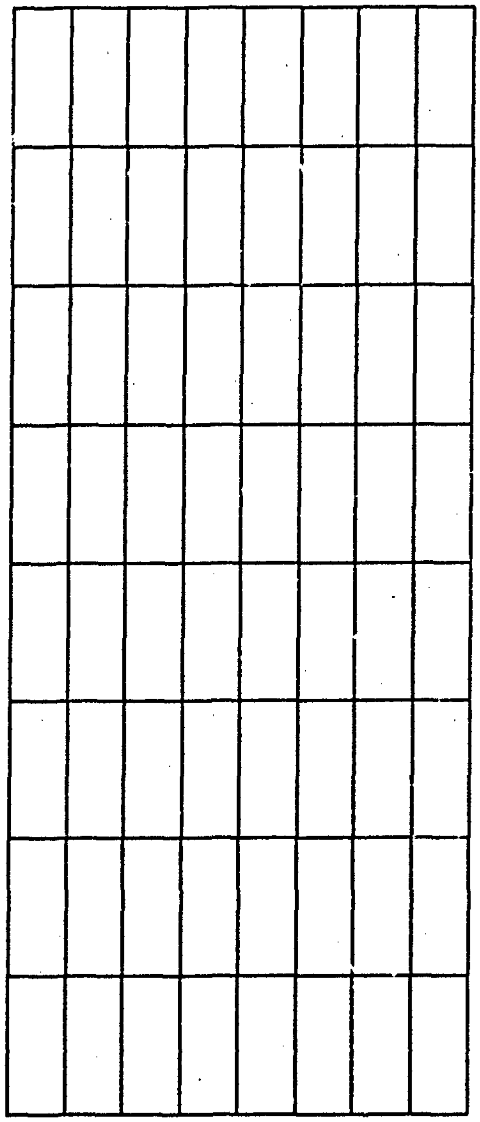


Figure A.3. Dispersion rectangle for 60mm mortar, range = 3000m.

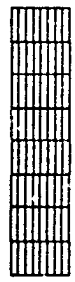


Figure A.4. Dispersion rectangle for 81mm mortar, range = 1000m.

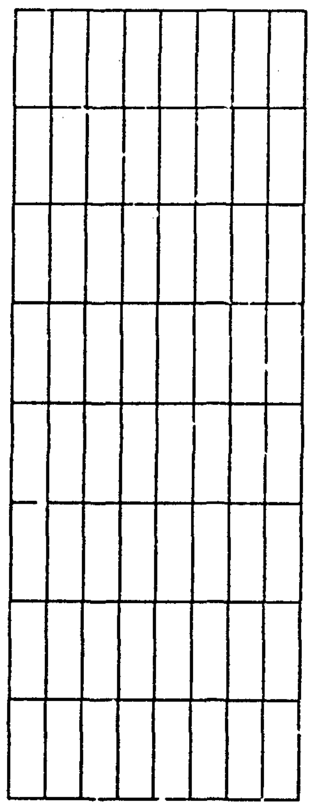


Figure A.5. Dispersion rectangle for 81mm mortar, range = 3000m.

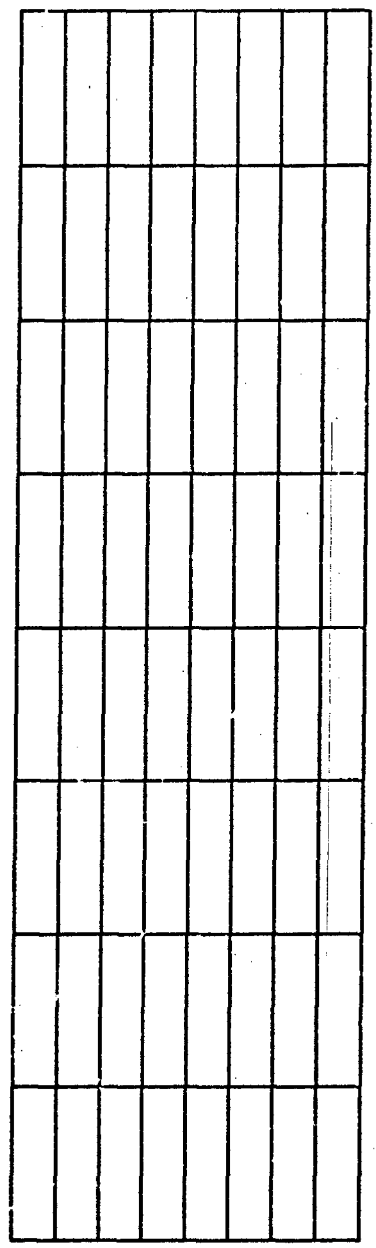


Figure A.6. Dispersion rectangle for 81mm mortar, range = 4500m.

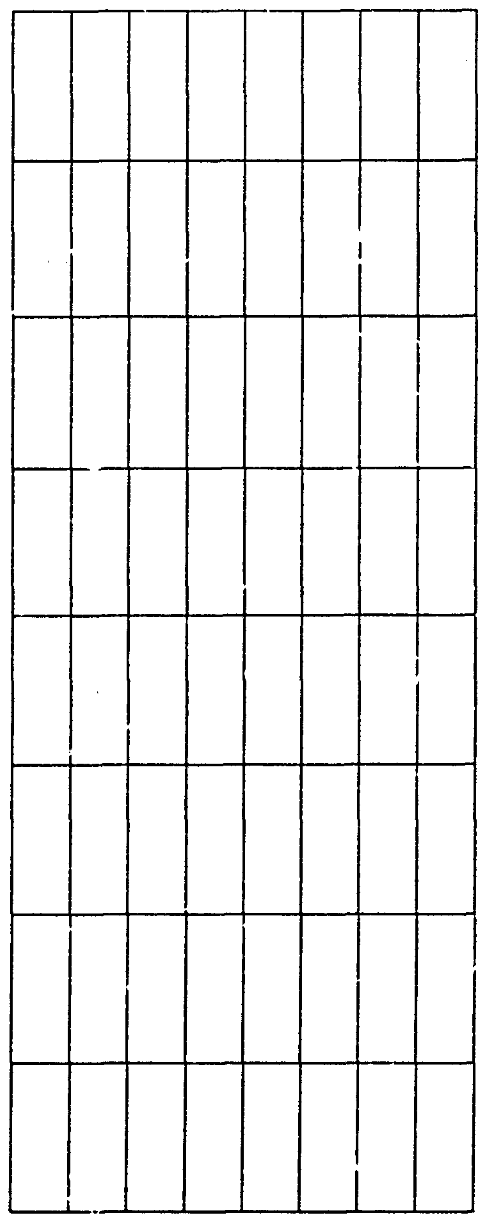


Figure A.7. Dispersion rectangle for 4.2in mortar, range = 3000m.

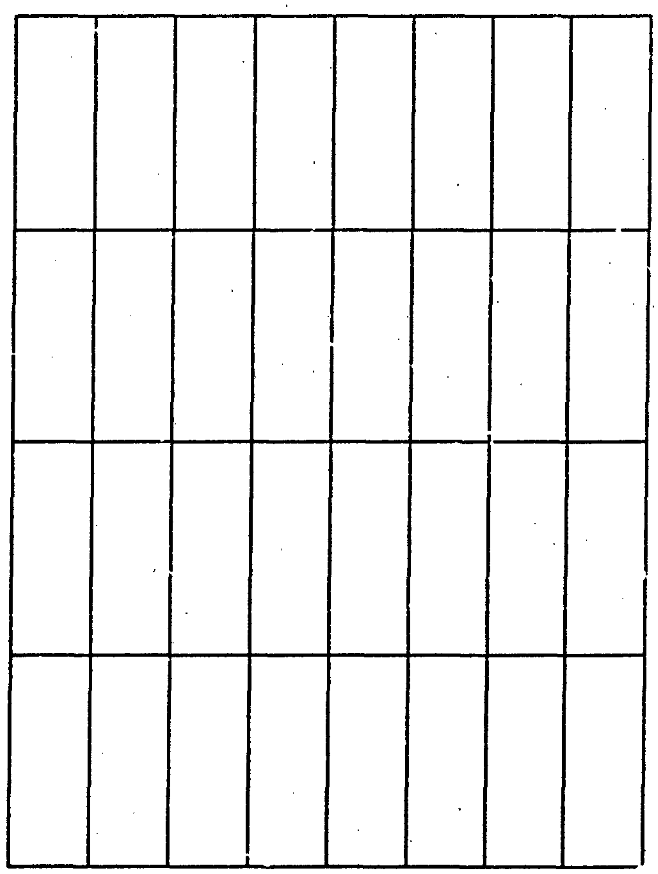


Figure A.8. Half dispersion rectangle for 4.2in mortar, range = 4000m.

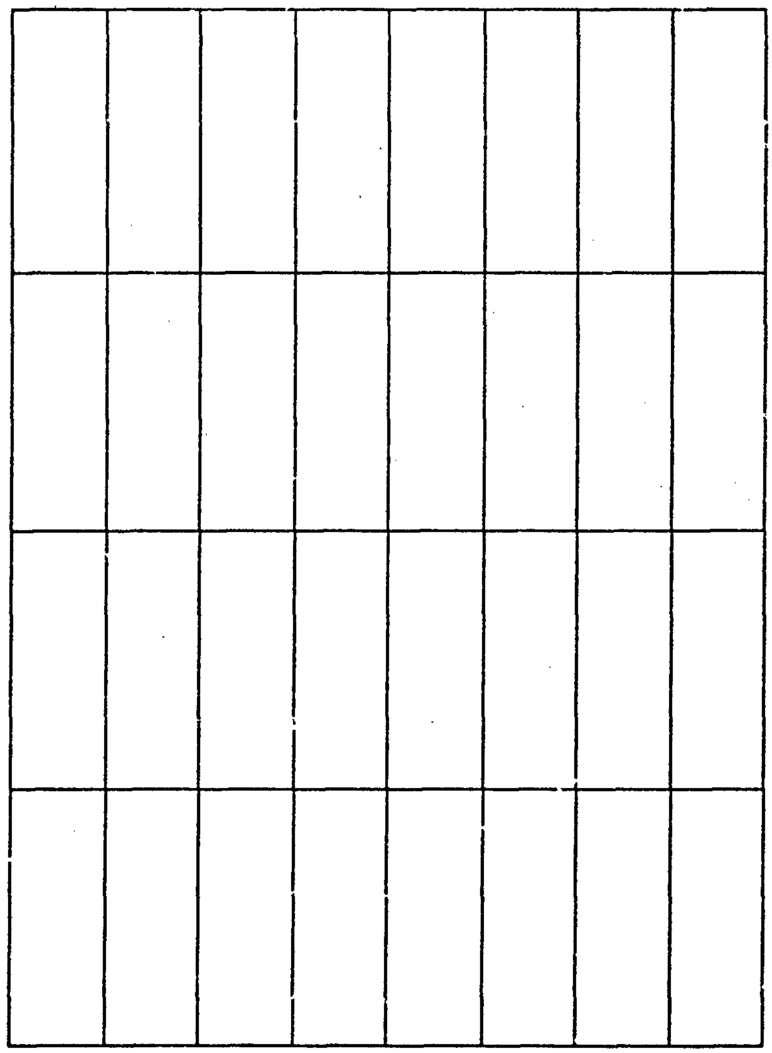


Figure A.9. Half dispersion rectangle for 4.2in mortar, range = 5000m.

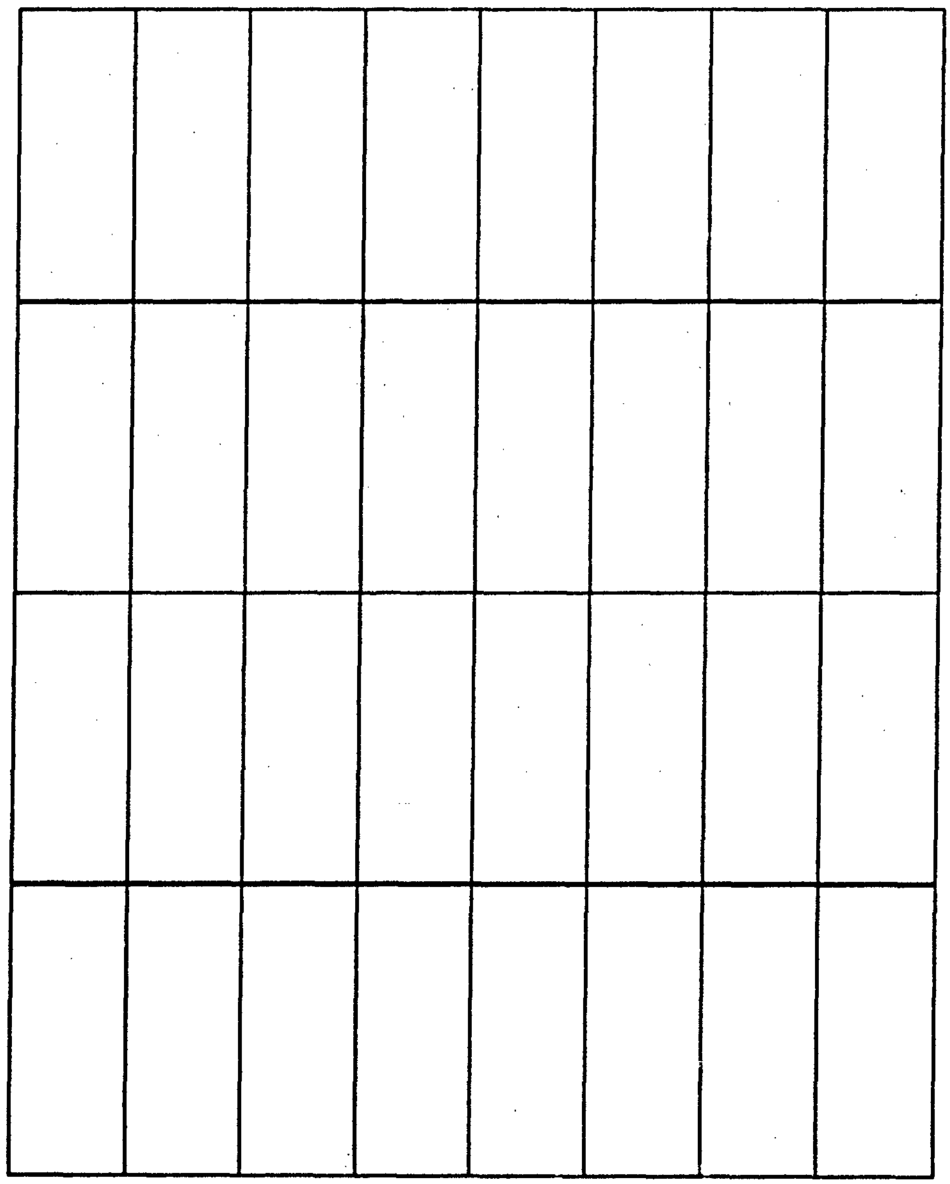


Figure A.10. Half dispersion rectangle for 4.2in mortar, range = 6000m.

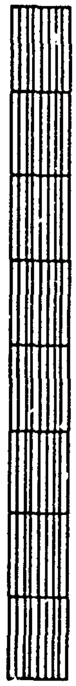


Figure A.11. Dispersion rectangle for 105mm howitzer, range = 2km.

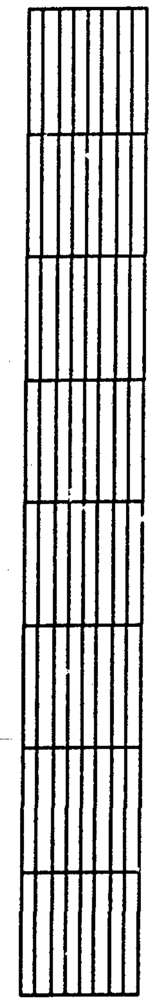


Figure A.12. Dispersion rectangle for 105mm howitzer, range = 3km.

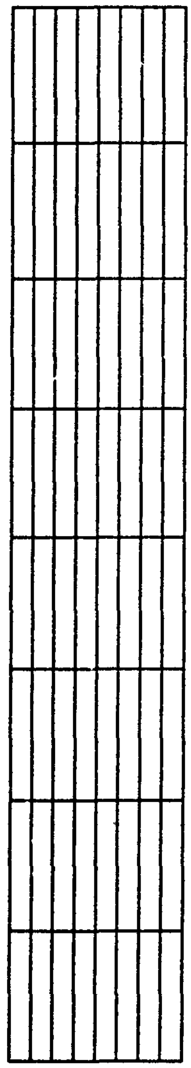


Figure A.13. Dispersion rectangle for 105mm howitzer, range = 5km.

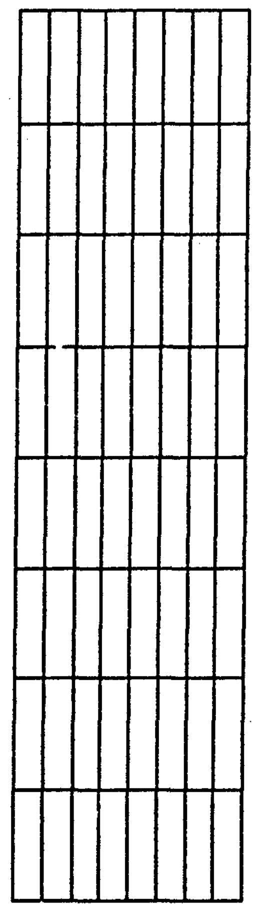


Figure A.14. Dispersion rectangle for 105mm howitzer, range = 7km.

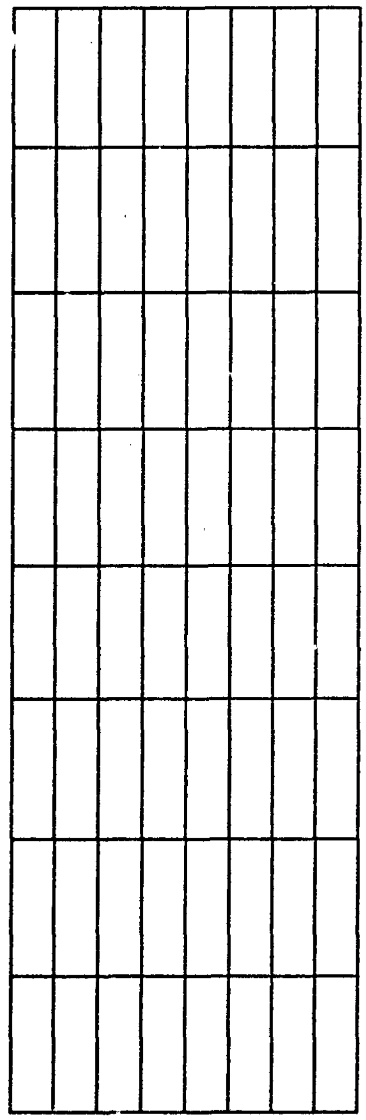


Figure A.15. Dispersion rectangle for 105mm howitzer, range = 9km.

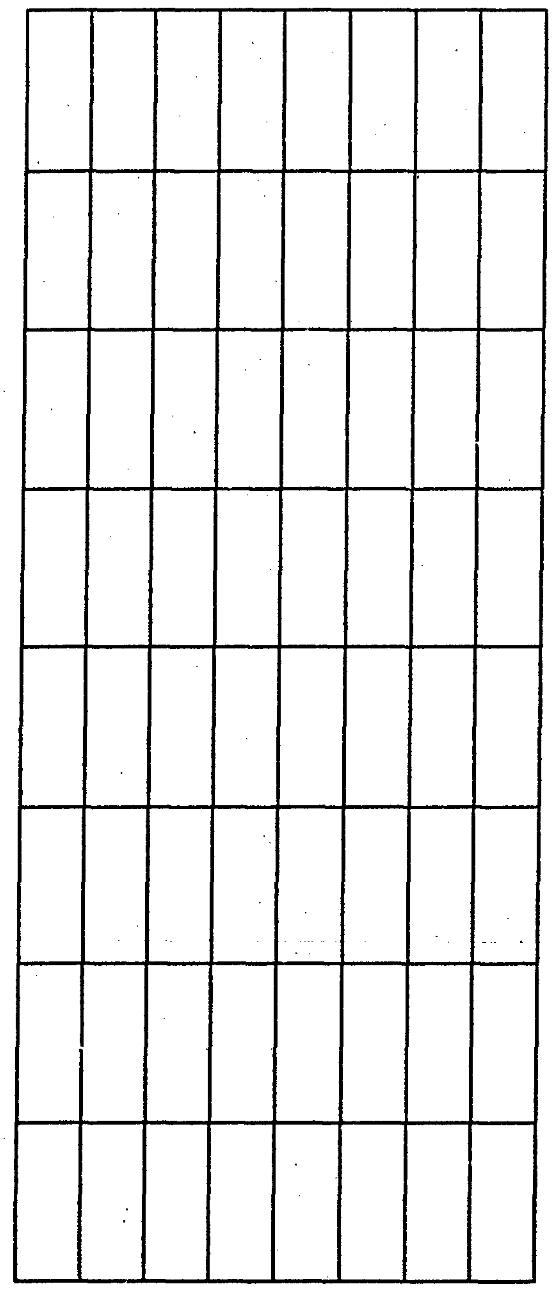


Figure A.16. Dispersion rectangle for 105mm howitzer, range = 11km.

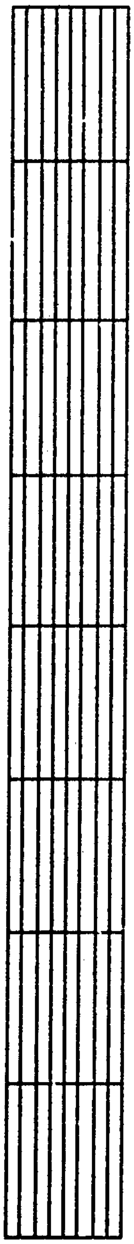


Figure A.17. Dispersion rectangle for 155mm howitzer, range = 3km.

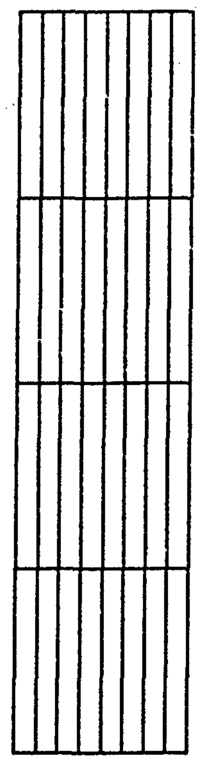


Figure A.18. Half dispersion rectangle for 155mm howitzer, range = 4km.

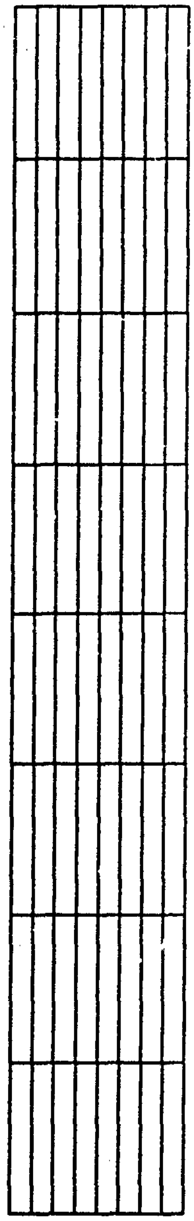


Figure A.19. Dispersion rectangle for 155mm howitzer, range = 6km.

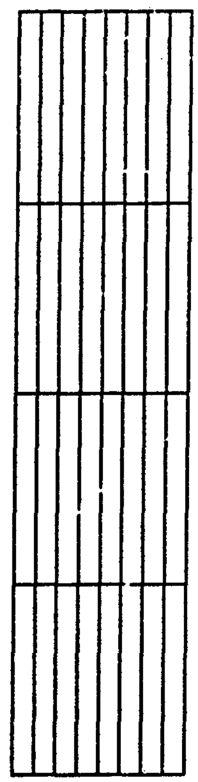


Figure A.20. Half dispersion rectangle for 155mm howitzer, range = 8km.

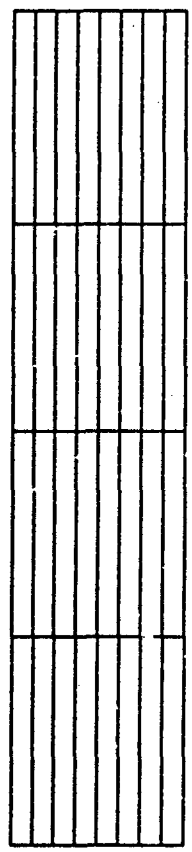


Figure A.21. Half dispersion rectangle for 155mm howitzer, range = 10km.

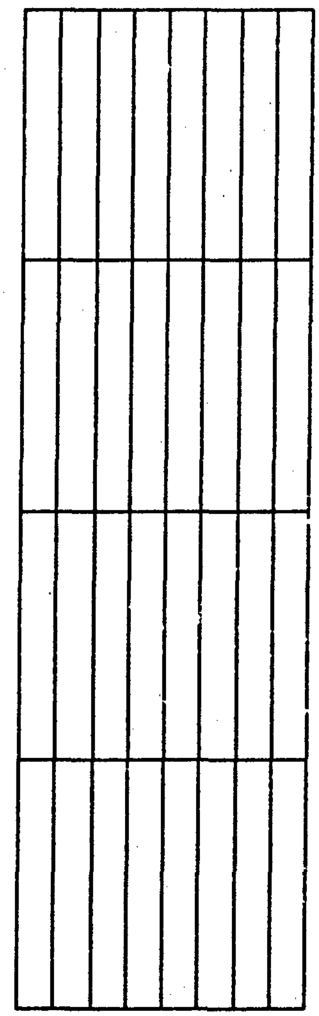


Figure A.22. Half dispersion rectangle for 155mm howitzer, range = 12km.

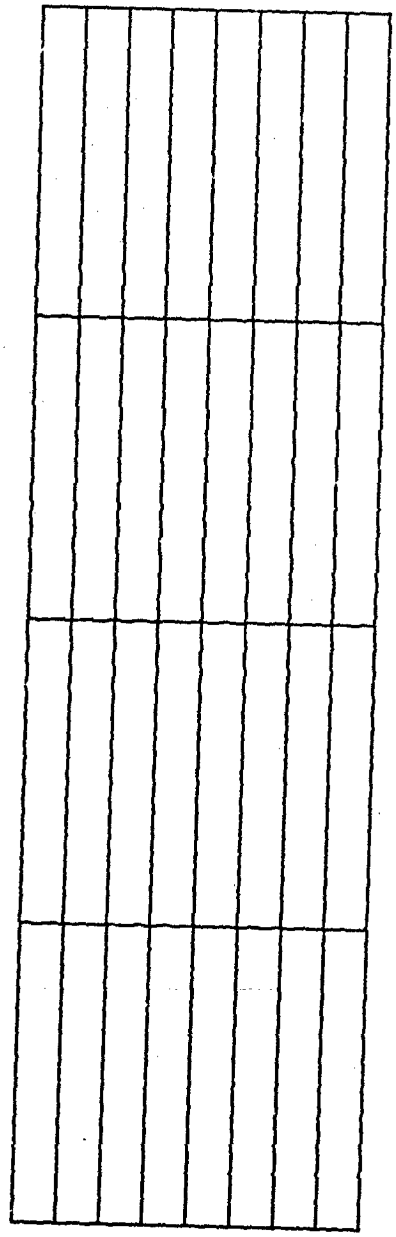


Figure A.23. Half dispersion rectangle for 155mm howitzer, range = 14km.

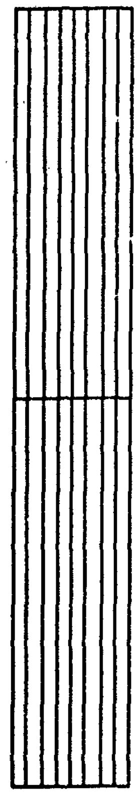


Figure A.24. Quarter dispersion rectangle for 175mm field gun, range = 6km.

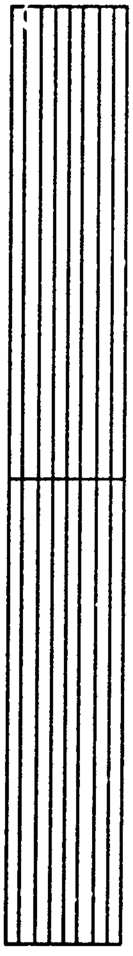


Figure A.25. Quarter dispersion rectangle for 175mm field gun, range = 10km.

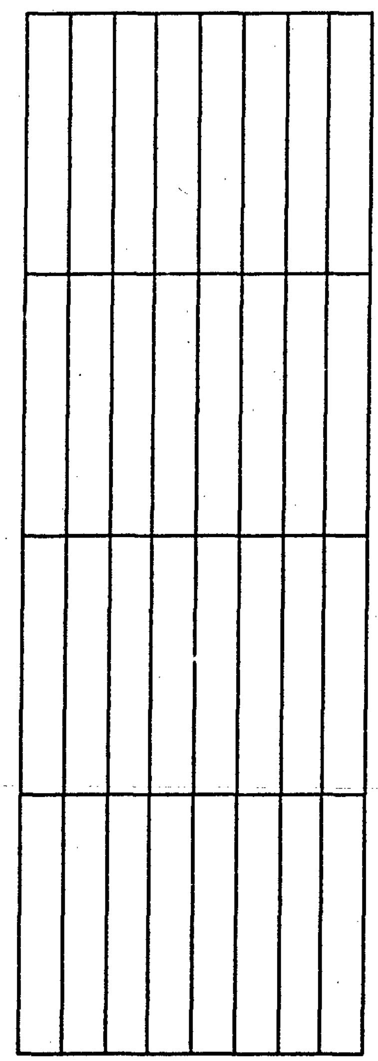


Figure A.26. Half dispersion rectangle for 175mm field gun, range = 14km.

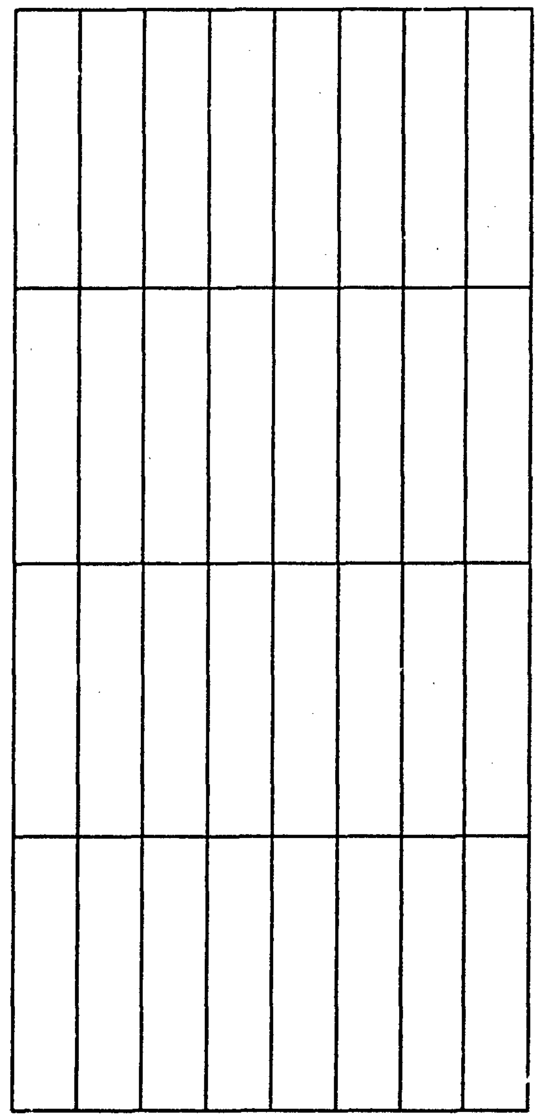


Figure A.27. Half dispersion rectangle for 175mm field gun, range = 18km.

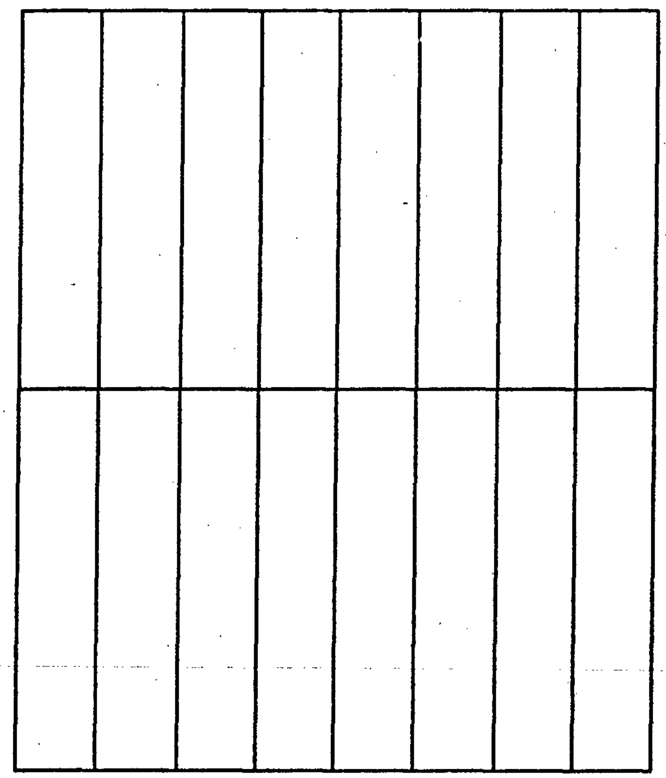


Figure A.28. Quarter dispersion rectangle for 175mm field gun, range = 22km.

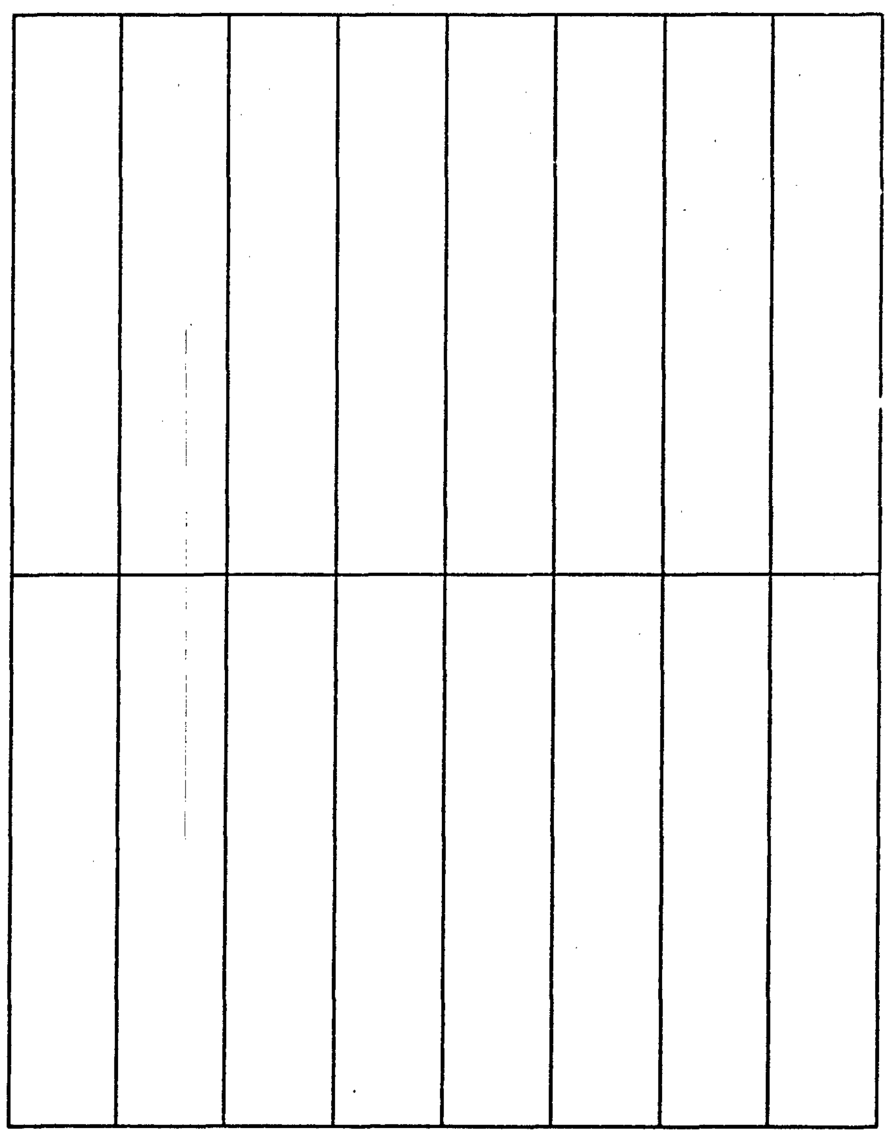


Figure A.29. Quarter dispersion rectangle for 175mm field gun, range = 28km.

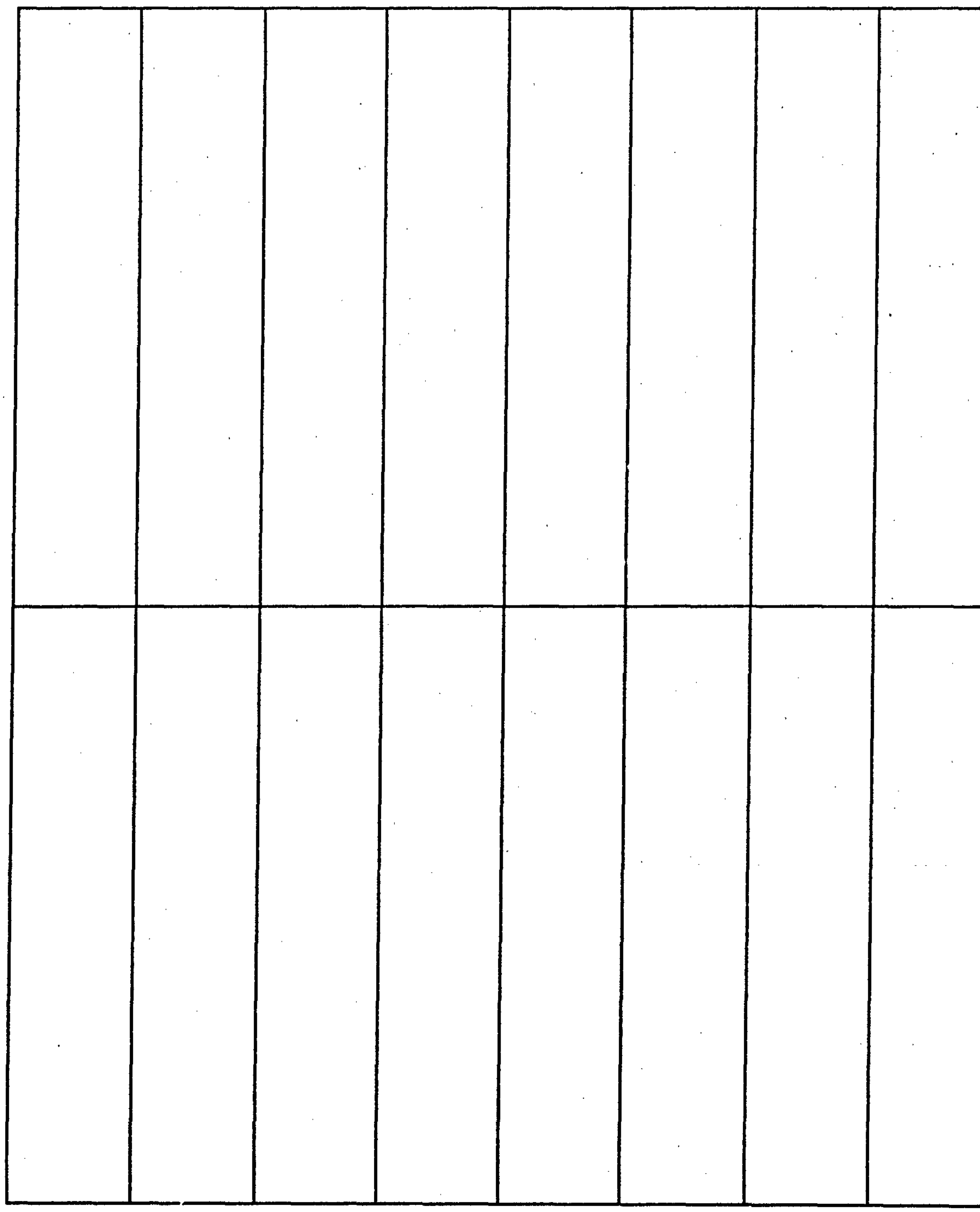


Figure A.30. Quarter dispersion rectangle for 175mm field gun, range = 32km.

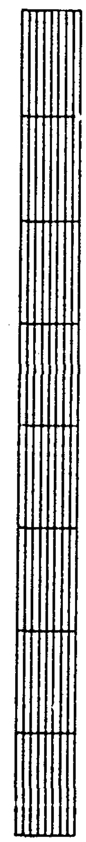


Figure A.31. Dispersion rectangle for 8in howitzer, range = 4km.

Figure A.32. Dispersion rectangle for 8in howitzer, range = 6km.

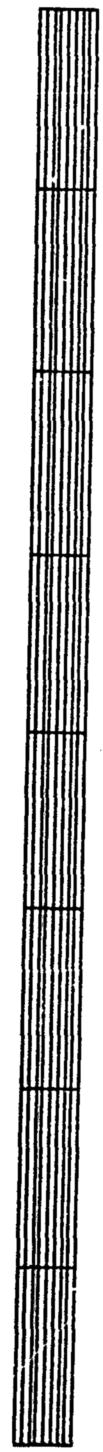


Figure A.33. Dispersion rectangle for 8in howitzer, range = 8km.

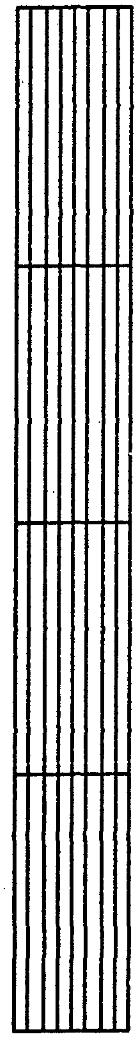


Figure A.34. Half dispersion rectangle for 8in howitzer, range = 10km.

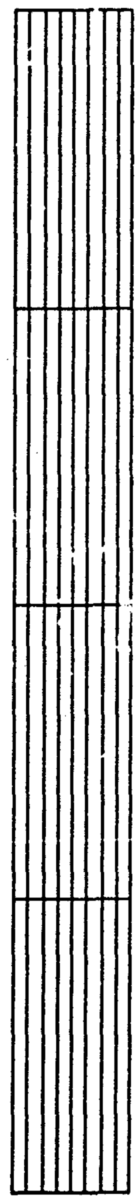


Figure A.35. Half dispersion rectangle for 8in howitzer, range = 12km.

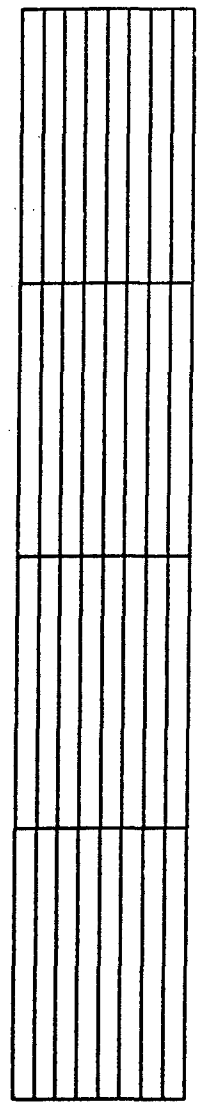


Figure A.36. Half dispersion rectangle for 8in howitzer, range = 14km.

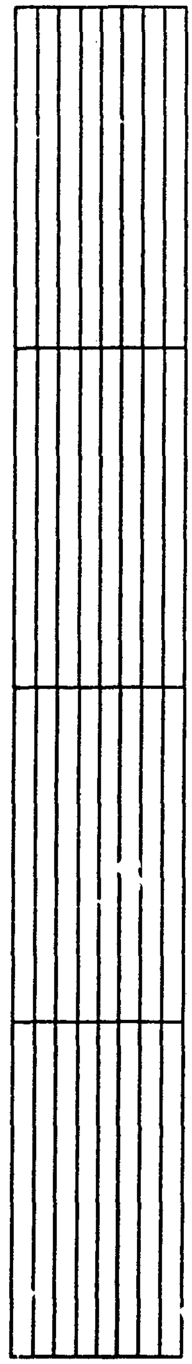


Figure A.37. Half dispersion rectangle for 8in howitzer, range = 16km.

Appendix B. Weapon Descriptions and Users

This appendix is intended to give a brief outline of the capabilities and specifications of each of the weapons examined in this study. The countries that use these wepons or weapons of similar calibre are included to show the widespread use of the weapons used in this study. The fact that these weapons are used by so many countries validates their use as threats against allied operations.

B.1 Field Guns

This section provides background information for the four field guns discussed in this work.

B.1.1 105mm Howitzer M102. The M102 is a light towed howitzer first fielded in 1965 as a replacement for the M101 105mm howitzer. Its main advantage is that it is much lighter than the M101 and can quickly traverse through 360 degrees to engage targets in any sector.

SPECIFICATIONS

Calibre: 105mm

Weight: 1496kg

Rate of Fire: 10 rds/min

Elevation/Depression: $+75^o/-5^o$

Max Range: 11500m (HE warhead)

Traverse: 360^o

Crew: 8

The M101, M102, and other howitzers of this calibre are used by: Argentina, Austria, Belgium, Bolivia, Brazil, Canada, Chile, Cambodia, Columbia, Denmark, Dominican Republic, Ecuador, El Salvador, Finland, France, Germany, Greece, Guatamala, Haiti, Honduras, India, Indonesia, Iraq, Ireland, Israel, Italy, Japan, Jordan, Kuwait, Laos, Lebanon, Libya, Malaysia, Mexico, Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Philippines, Portugal, Romania, Qatar, Saudi Arabia, Singapore, South Korea, Spain, Sudan, Sweden, Switzerland, Taiwan, Thailand, Tunisia, Turkey, UK, USA, Uraguay, Vietnam, Yemen, Yugoslavia, and others.

B.1.2 155mm Howitzer M109. The M109 is self-propelled medium howitzer first produces in 1962. The M109 has undergone continued developnent throughout its production run which exceeded 4000 units in 1979. The current model being produced for the U.S. Army is the M109A6 Paladin featuring advanced new fire control electronics and improved firing and mobility systems. In this study and in the specifications below, M109A1 data was used.

SPECIFICATIONS

Calibre: 155mm

Secondary Armament: 12.7mm anti-aircraft machine gun

Max Road Speed: 60km/hr

Rate of Fire: 3 rds/min

Elevation/Depression: $+75^o/-5^o$

Max Range: 14600m

Traverse: 360^o

Crew: 6

The M109 series of howitzers, and other howitzers of this calibre are used by: Argentina, Austria, Brazil, Canada, Chile, Denmark, Ecuador, El Salvador, France, Germany, Greece, Honduras, India, Italy, Japan, Laos, Malaysia, Netherlands, Norway, Pakistan, Philippines, Singapore, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, UK, USA and others.

B.1.3 175mm Howitzer M107. The M107 is a self-propelled which was designed as one of the members of a family of self-propelled guns sharing many common features. The early 1960s saw the first deployment of the M107. Production was concluded in 1980 by which time 524 machines had been produced. The M107 used new technology to greatly reduce the vehicle's weight and thereby make it air-transportable. Currently all M107s owned by the U.S. have been converted to the latest model of the M110, the other member of the proposed family of guns to actually be produced.

SPECIFICATIONS

Calibre: 175mm

Secondary Armament: none

Max Road Speed: 56km/hr

Rate of Fire: 2 rds/min

Elevation/Depression: $+65^o/-2^o$

Max Range: 32000m

Traverse: 30^o right or left

Crew: 5 (A total of thirteen crewman operate the gun)

The M107 and guns of similar calibre (180mm) are currently used by: China, Egypt, India, Iraq, South Africa, Syria and others. Many users of the M110 8in Howitzer currently operate M107s upgraded to M110A2 status.

B.1.4 8in Howitzer M110. The M110 series of 8in (203mm) self-propelled howitzers come from the same family as the M107. Also an air-transportable weapon, the barrel is interchangeable with 175mm and 155mm guns using a common mount. Original production ended in the late 1960s, by which time over 750 vehicles had been produced. During the 1980s another short production run was undertaken to complete the requirements of the U.S. Army. Like the M107, the M110 is an open-top vehicle with no protection for the crew from enemy forces or Nuclear-Biological-Chemical (NBC) conditions. Specifications given are for the original version of the M110.

SPECIFICATIONS

Calibre: 8in (203mm)

Secondary Armament: none

Max Road Speed: 56km/hr

Rate of Fire: 2 rds/min

Elevation/Depression: $+65^o/-2^o$

Max Range: 16800m

Traverse: 30^o right or left

Crew: 5 (A total of thirteen crewman operate the gun)

The M110 and other artillery of this calibre are operated by: Belgium, Denmark, Germany, Greece, Iran, Israel, Italy, Japan, Jordan, Netherlands, Pakistan,

Qatar, South Korea, Spain, Taiwan, Turkey, USSR, United Kingdom, USA, Yugoslavia and others.

B.2 Mortars

This section provides information for U.S. mortars of the calibres used in this study.

B.2.1 60mm Mortar. The M224 is th U.S. Army's standard lightweight company mortar. The M224 was developed during the Vietnam War as a replacement for the obsolete M19 60mm mortar. It was originally designed to take the place of the 81mm mortar in the Infantry, Airmobile Infantry, and Airborne Infantry. The weapon was designed to deliver high volumes of fire at either high or low angle fire. With its light rectangular baseplate and hand-held operation, the entire mortar weighs only 7.8 kilograms. It was developed at the Watervliet and Picatinny arsenals and was placed in production in 1977. A maximum rate of thirty rounds per minute may be achieved with this weapon. Up to eighteen rounds per minute may be fired for longer periods of time.

60mm mortars are very widely used. Mortars of this calibre are used by: Austria, Belgium, Benin, Bolivia, Brazil, Burkina Faso, Cameroon, Canada, Central African Rpublic, Chad, Chile, China, Columbia, Denmark, Djibouti, El Salvador, Ethiopia, Finland, France, Greece, Guatemala, Haiti, Honduras, Indonesia, Iran, Ireland, Japan, Lebanon, Liberia, Madagascar, Mauritania, Mexico, Morocco, Niger, Nigeria, Oman, Pakistan, Panama, Portugal, Sierra Leone, Singapore, South Africa, South Korea, Spain, Switzerland, Taiwan, Thailand, Trinidad and Tabago, Tunisia, Turkey, USA, Venezuela, Vietnam, Yugoslavia, Zaire and others.

B.2.2 81mm Mortar. The M29 is a smoothbore, muzzle-loaded weapon. It is consists of the barrel, the baseplate, and the mount, plus the sight. It is used as a ground weapon or mounted on an M113 derived vehicle, thus making the M125

Carrier Mortar. The mount of the weapon consists of the bipod legs and the elevation and traversing mechanisms. Two different sights are available for the weapon and each has two different ways of sighting. The weapon was developed by the Watervliet Arsenal and is currently in production. Maximum rate of fire is twenty-five rounds over two minutes. Eight rounds per minute can be sustained indefinitely.

Mortars of this size are generally considered to be medium mortars. Mortars of the 81mm and 82mm (developed by the Soviets) size are used by almost every country listed in Jane's 1992-93 inventory of weapons(13)[777-787]. By their listing, at least 143 countries have mortars of 81mm or 82mm muzzle diameter.

B.2.3 4.2in (107mm) Mortar. The M30 is a rifled, muzzle-loaded, drop-fired heavy mortar which can be hand-carried for short distances when broken down into five sections. The M30 is usually mounted on a modified M113 vehicle and together are termed the M106 mortar carrier. It is currently the standard heavy mortar in the U.S. arsenal although production has ceased. It will probably be replaced by a new 120mm mortar in lieu of further improvement of this weapon. Its maximum rate of fire is eighteen rounds for one minute and then nine rounds per minute for up to five minutes.

Mortars of this calibre are currently in use with the armies of: Afganistan, Austria, Belgium, Bolivia, Brazil, Canada, Columbia, CIS, Cyprus, Equador, Ethippia, Greece, Guatemala, Iran, Laos, Liberia, Libya, Japan, Jordan, Mexico, Nepal, Netherlands, Norway, Oman, Paraguay, Philippines, Portugal, Saudi Arabia, Sri Lanka, South Korea, Thailand, Tunisia, Turkey, USA, Uraguay, Vietnam, Zaire, and others.

B.3 Infantry Weapons

This section covers the weapons discussed in Chapter 3 as well as some other weapons that are widely used by the world's armies.

B.3.1 RPG Family of Weapons. The RPG-7 is probably the most well known and most used weapon in this family of weapons. The first was the RPG-2. Subsequent models are the RPG-16, -18, and -22. The RPG-7 is still the standard manportable short-range anti-tank weapon of the former Warsaw Pact countries. These weapons are all simple tubes, with simple graduated sights mounted on them. The missiles themselves are the high-explosive anti-tank (HEAT) type or standard HE warheads. These weapons are used by all former Warsaw Pact countries, and in general use in Africa, Asia, and throughout the Middle East. Practical range is out to 500m for the RPG-7 and up to 800m for the improved RPG-16.

B.3.2 AT Family of Guided Missiles. This family of medium anti-armor guided missile. The AT-4, -5, and -7, are optically/infared guided missiles similar to the U.S. Dragon anti-tank missile. Development of these missiles began in the 1960s to replace the older Sagger family of optically guided missiles. The AT-4 has a range of 2000-2500m, the AT-5 has a range of 4000m, and the AT-7 has a range of 1000m. These missiles are used by all of the former Warsaw Pact countries and by most other countries that operate Soviet armor systems.

B.3.3 M72 HEAT Launcher. Initially produced in the early 1960s, the M72 LAW (Light Anti-tank Weapon) was lightweight, cheap, and easy to use. Current production versions are the "E" series which feature much improved rocket motor and more powerful warheads. The system fires an unguided rocket out to about 1000m. The launch tube is expendable and the whole system weighs only 2.5–3.5kg. This weapon first saw widespread use in the Vietnam War and is still in production. The weapon is used by most NATO countries including the United States and is also widely used throughout the rest of the world.

B.3.4 Recoiless Rifles. This type of weapon is widely used throughout the world and is made in several calibres, the most widely used being 90mm and 106mm

(these are the calibres used in U.S. production). By venting explosive gases out the rear of the weapon at the time it is fired, very little recoil is encountered. This being the case, there is no need for heavy mounts and these weapons are easily used by infantry and can be mounted on any type of light vehicle. They were first used in the 1950s but are still found in substantial numbers throughout the world.

B.3.5 Dragon Medium Anti-Armor Missile System. The Dragon is a one-manporatable weapon capable of defeating main battle tanks. It is highly accurate against both stationary and moving targets and its lightweight and compact size makes it ideal for airborne and light infantry use. This weapon has gone through three major improvement programs, with the last two types still being in production. Its range is from 65-1000m and its capabilities are similar to most other current generation medium anti-tank guided missiles. The Dragon is used by Iran, Israel, Jordan, Morroco, Netherlands, USA, Yugoslavia, and others.

B.3.6 TOW Heavy Anti-Tank Missile System. The Tube-launched, Optically tracked, Wire guided (TOW) missile is a man-portable, vehicle mounted or helicopter carried heavy anti-tank weapon. It was widely used in Vietnam, the Arab-Israeli Wars and most recently in Desert Storm. Since 1970, it has a hit probability of over 93% in over 12,000 test and training firings. It is effective from 65 to 3750 meters and has been sold to over forty countries throughout the world. Production is still currently underway and over 460,000 units have already been made.

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Airlifter attrition can severly decrease the throughput of cargo duri extended airlift operations. Much work has been done to enhance the tactical airlifter survivability in the air butlittle study has gone into airlifter survivability on the ground.
This thesis develops a method to measure the threat to parked aircraf from ground weapons. Specific scenarios cover airlifter mobility on ground, time to off-load cargo, short-field takeoff capability and attack by infantry weapons. A weapon is examined at each of several firing ranges to target. The threat to the aircraft is measured as t probability that the aircraft is hit.
Data on accuracy and lethality comes from several U.S. Army sources. Results of the research is used to evaluate several ideas currently being studied to improve airlifter survivability. Also, information presented regarding the factors having the greatest impact on ground survivability.

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